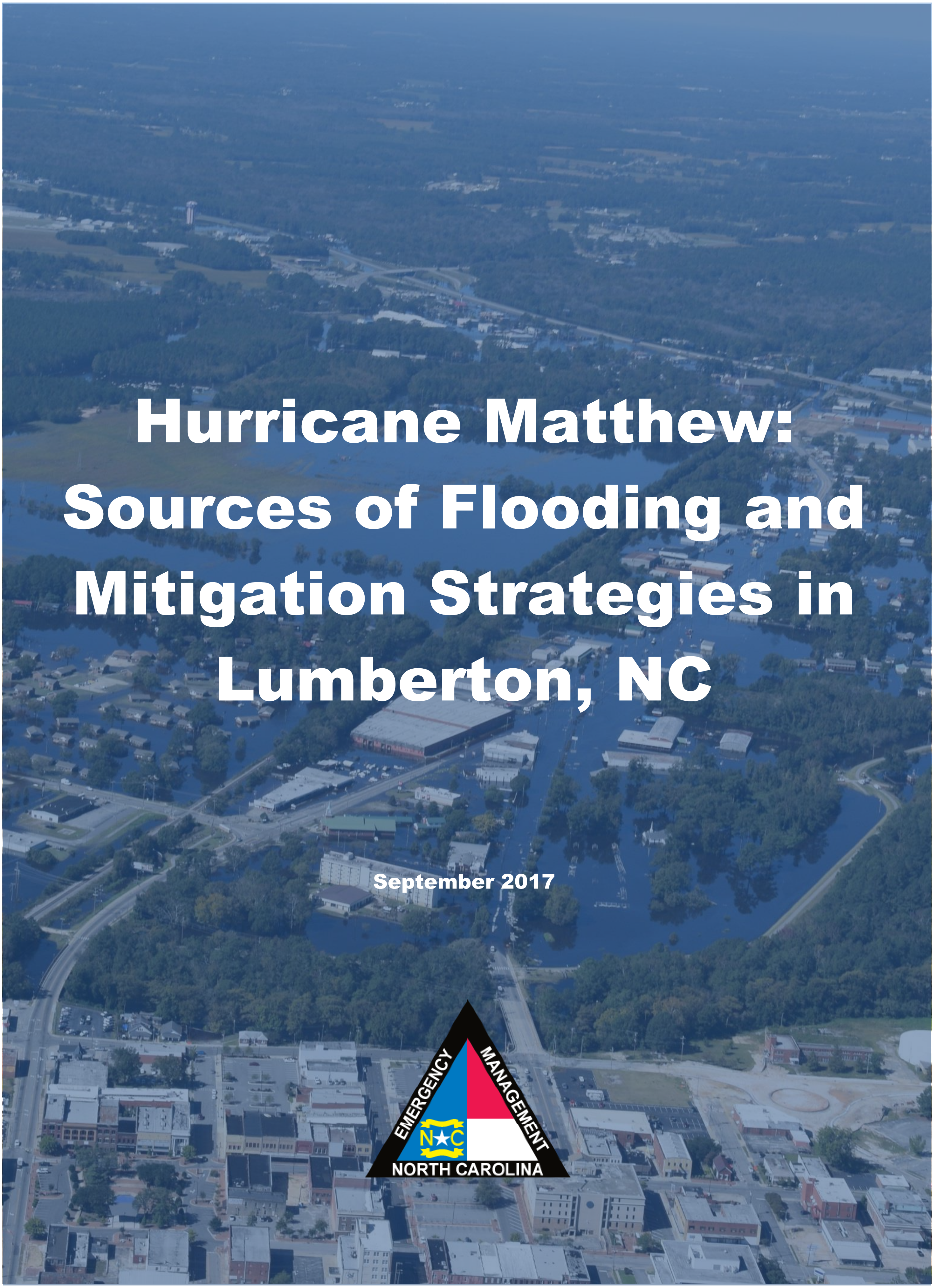


Hurricane Matthew: Sources of Flooding and Mitigation Strategies in Lumberton, NC

September 2017

EMERGENCY MANAGEMENT
NORTH CAROLINA

Contents

List of Acronyms

AREMA – American Railway Engineering and Maintenance-of-way Association

BFE – Base Flood Elevation

CFR – Code of Federal Regulations

CFS – Cubic Feet per Second

FEMA – Federal Emergency Management Agency

FIS – Flood Insurance Study

HEC-RAS – Hydraulic Engineering Center River Analysis System

LiDAR – Light Detection and Ranging

NAVD – North American Vertical Datum

NCDOT – North Carolina Department of Transportation

NCEM – North Carolina Emergency Management

NCFMP – North Carolina Floodplain Mapping Program

NFIP – National Flood Insurance Program

NRCS – Natural Resources Conservation Service

RCP – Reinforced Concrete Pipe

RRP – Resilient Redevelopment Plan

SCS – Soil Conservation Service

USACE – United States Army Corps of Engineers

USGS – United States Geologic Survey

Executive Summary

The Lumber River and the Jacob Swamp Watershed in Robeson County has a long history of flooding problems. In the 1960s the Jacob Swamp Watershed Improvement Plan was developed by the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), to mitigate the flooding issues and allow for safer development of the land for commercial, agricultural, and residential uses. These improvements included widening and deepening of drainage channels, construction of a levee system along the Lumber River that included an earthen berm that connected I-95 to the north to Alamac Road (SR 2289), and operation and maintenance plans to maintain the channels and levee system.

On October 8, 2016 intense rain from Hurricane Matthew began to fall in the City of Lumberton and across the Lumber River watershed. This rainfall continued into October 9th and resulted in Lumberton receiving a total of approximately 12 inches of rain. This amount of rain likely resulted in widespread localized flooding. In the early morning hours of October 10, the Lumber River overwhelmed the sandbagging effort at the VFW Road underpass and water from the river began flowing into the area ostensibly protected by the levee system. The floodwaters washed out the railroad and overtopped VFW Road resulting in flood water depths of greater than four feet in many areas, including at the City water treatment plant. The flooding in the City had several contributing factors, including flooding on interior drainage channels and backwater from the Lumber River, but the major contributing factor to the devastation was the inflow of floodwater through the VFW Road underpass. Investigation of the reach of the levee between I-95 and Alamac Road did not show any signs that the levee was compromised in any way. Please note that any elevations referenced in this report are referenced to NAVD 88.

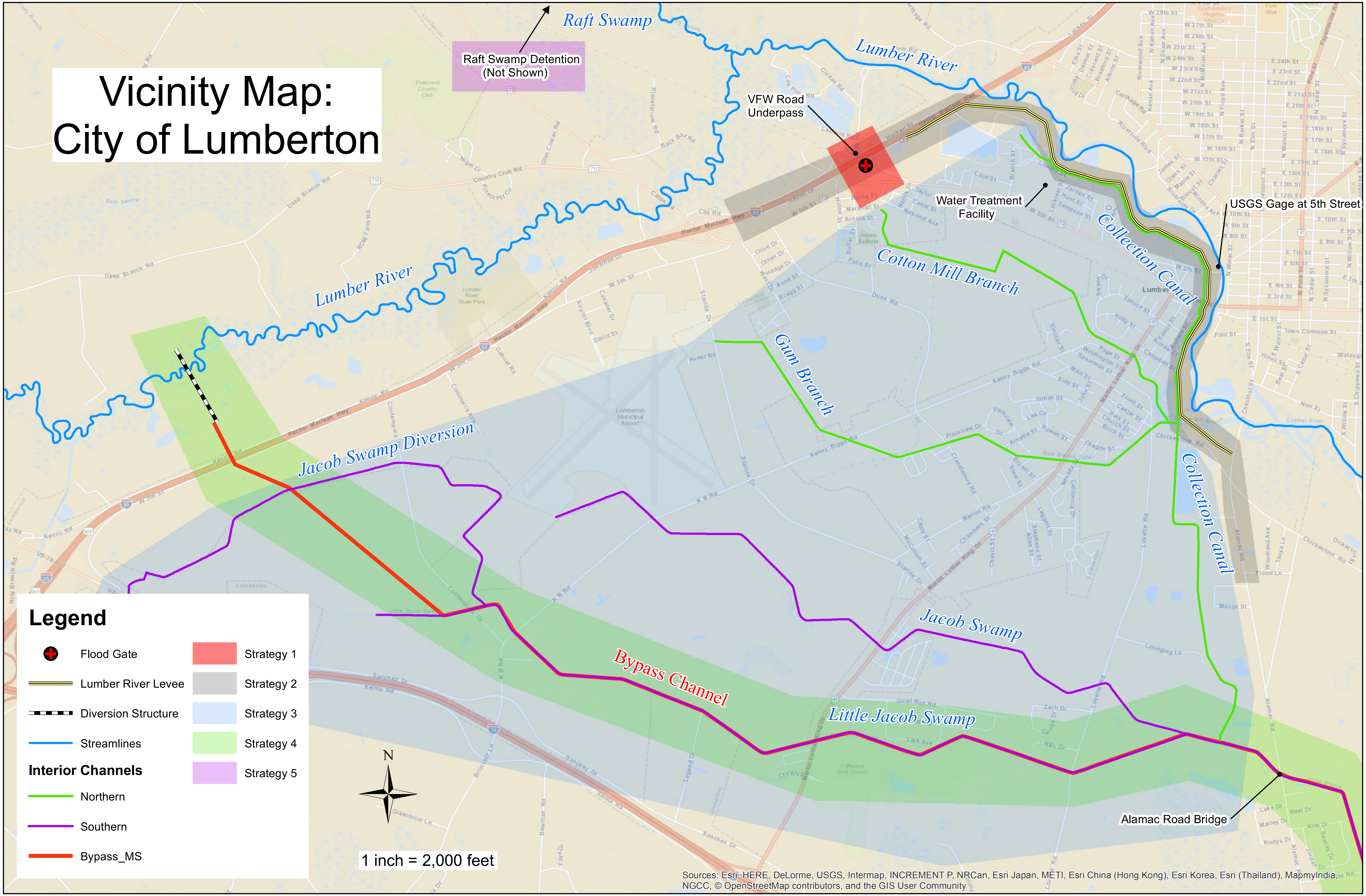
Mitigation Alternatives

For this planning level analysis, five mitigation options were investigated. This report includes a discussion of each option as well as rough costs and losses that would be avoided during a 1 percent annual chance flood were the mitigation option in place. Table 1 shows the results of the analysis. Direct losses include estimates of losses based on structural damage and loss of property and contents. Indirect losses include estimates for relocation costs, lost income and wages, lost sales, and lost rent.

Table 1: Comparison Table for Losses Avoided/Cost

Strategy	Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
Strategy 1 – Installation of Flood Gate	$ 486,500	$ 1,913,049	$ 3,453,755	3.93	11.0
Strategy 2 – Enhancements to Levee	$ 3,441,500	$ 1,913,049	$ 3,453,755	0.56	1.56
Strategy 3 – Improvements to Interior Drainage Channels	$ 19,496,250	$ 15,665,294	$ 39,328,554	0.82	2.82
Northern Channels	$ 7,818,750	$ 15,135,618	$ 39,114,519	1.94	6.94
Southern Channels	$ 11,191,000	$ 2,260,703	$ 3,586,517	0.20	0.52
Strategy 4 – Diversion of Lumber River	$ 68,152,500	$ 13,150,024	$ 65,653,429	0.19	1.16
Strategy 5 – Construction of Impoundment on Raft Swamp	$ 60,306,500	$ 7,720,836	$ 31,452,438	0.13	0.52

The map insert titled "Vicinity Map: City of Lumberton" provides an overview of the area of interest including critical locations and features discussed in this report.


Vicinity Map:
City of Lumberton
Raft Swamp
Raft Swamp Detention
(Not Shown)
Lumber River
VFW Road
Underpass
Water Treatment
Facility
USGS Gage at 5th Street
Cotton Mill Branch
Collection Canal
Gum Branch
Jacob Swamp Diversion
Jacob Swamp
Bypass Channel
Little Jacob Swamp
Alamac Road Bridge
Legend
Flood Gate
Lumber River Levee
Diversion Structure
Streamlines
Interior Channels
Northern
Southern
Bypass_MS
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Strategy 5
N
1 inch = 2,000 feet
Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Findings and Recommendations

Based on this planning level study, the recommendations to alleviate flooding in and around Lumberton are as follows:

- Installation of a flood gate at VFW Road underpass. The cost of the flood gate installation is estimated at approximately $500,000 and a conservative estimate of the direct losses avoided during a 1 percent annual chance flood is approximately $2,000,000. Assuming the levee performs as it did during Hurricane Matthew, the flood gate would potentially prevent sustained flooding behind the levee as well as protect the water treatment facility. It is recommended that a temporary flood barrier solution, such as HESCO baskets, be staged near the proposed flood gate location so protection can be established in the event of a flood while the flood gate is in planning and construction phases.

- Updated engineering analysis should be conducted on all streams in the Jacob Swamp watershed using updated topographic data and more detailed modeling solutions. These updated modeling and mapping results should be used to determine where improvements need to be made to internal drainage channels to bring them to the 1% annual chance flood level of protection. Following the revised analysis, it is likely that improvements to the northern channels (Cotton Mill Branch, Gum Branch, and the Collection Canal) will show a benefit/cost ratio of greater than 1.0. This is the number 3 overall priority for Robeson County in the Robeson County Resilient Redevelopment Plan (RRP).

- Levee enhancements should be considered to allow the levee system to achieve certification and accreditation. This would provide confidence in the protection level for the community and could spur development. Accreditation would benefit those currently in the special flood hazard area by way of lower insurance rates. Reduction in flood insurance costs is not considered in the analysis. Levee Enhancements is the overall number 2 priority in the Robeson County RRP.

- In cooperation with NCDOT and as part of a levee certification effort, I-95 should be improved and the road bed elevated to achieve freeboard minimums to meet the criteria for levee certification. Survey would be required to determine the extent of the needed improvements. A secondary benefit to highway improvements would be to provide an additional transportation link during a major flood event such as what occurred with Hurricane Matthew.

- Construction of a bypass channel along the current path of Little Jacob Swamp and Jacob Swamp has a high cost with low returns by way of direct losses avoided and comparatively low return for total losses avoided. Further investigation of this option is not recommended.

- Construction of an impoundment on Raft Swamp is not recommended due to high estimated costs of construction and minimal flood reduction benefits.

- These recommendations are based on this analysis which was intended to be a very high level planning analysis. Implementation of any recommendations from this report requires a more detailed analysis for effectiveness, cost, and feasibility.

1. Background

1. Background

City of Lumberton and Hurricane Matthew Impacts

Lumberton is located in the Sandhills region of North Carolina in the central part of Robeson County. With a population of 21,721 it is the county seat and the largest city in the county. I-95 passes through Lumberton in a North-South orientation and is a major east coast transportation route. It is crossed from west to east by the Lumber River which is a major river in North Carolina and provides a source of recreation and scenic beauty for the citizens.

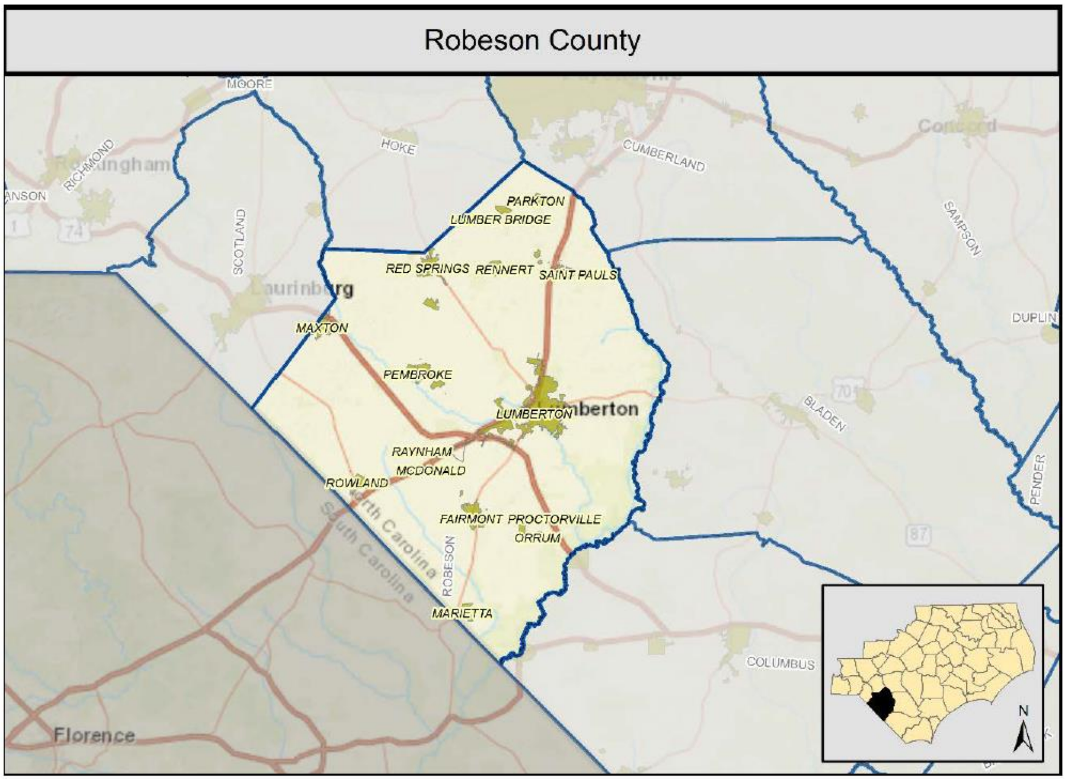


Figure 1: Lumberton and Robeson County

On Saturday October 8, 2016 Hurricane Matthew made landfall near McClellanville, South Carolina and began working its way up the South Carolina and North Carolina coastlines. The tropical moisture provided by the storm interacted with a frontal boundary to produce extreme rainfall over the eastern Piedmont and Coastal Plain counties of North Carolina with some areas reporting as much as 18 inches of rainfall over a 36-hour period. Record rainfall totals were seen in 17 counties in Eastern North Carolina. The widespread flooding that resulted from this heavy rainfall caused extensive damage to homes and businesses in the City of Lumberton and areas of the County, particularly those in the western and southern portions of the City. As a result of the flooding approximately 18,000 residents in Robeson County requested County assistance due to being displaced by flooding and over 1,800 residents in Robeson County requested assistance from the State of North Carolina and the Federal Emergency Management Agency (FEMA). The Hazard Mitigation Grant Program received 387 applications in Lumberton for flood relief. In addition to residential and commercial damage, infrastructure was severely impacted. Public Assistance claims, which are often closely tied to infrastructure, amounted to approximately 2.7 million dollars for the City of Lumberton as of March 20, 2017. Critically, the City water treatment plant, shown in Figure 2, was inundated with up to 4 feet of water which resulted in loss of potable water for the city for several days and orders to limit water use until temporary systems were in place on October 20th. The protection of the water plant and distribution system is a high priority for the City of Lumberton in the Robeson County Resilient Redevelopment Plan (RRP) published in May 2017 (Appendix E).

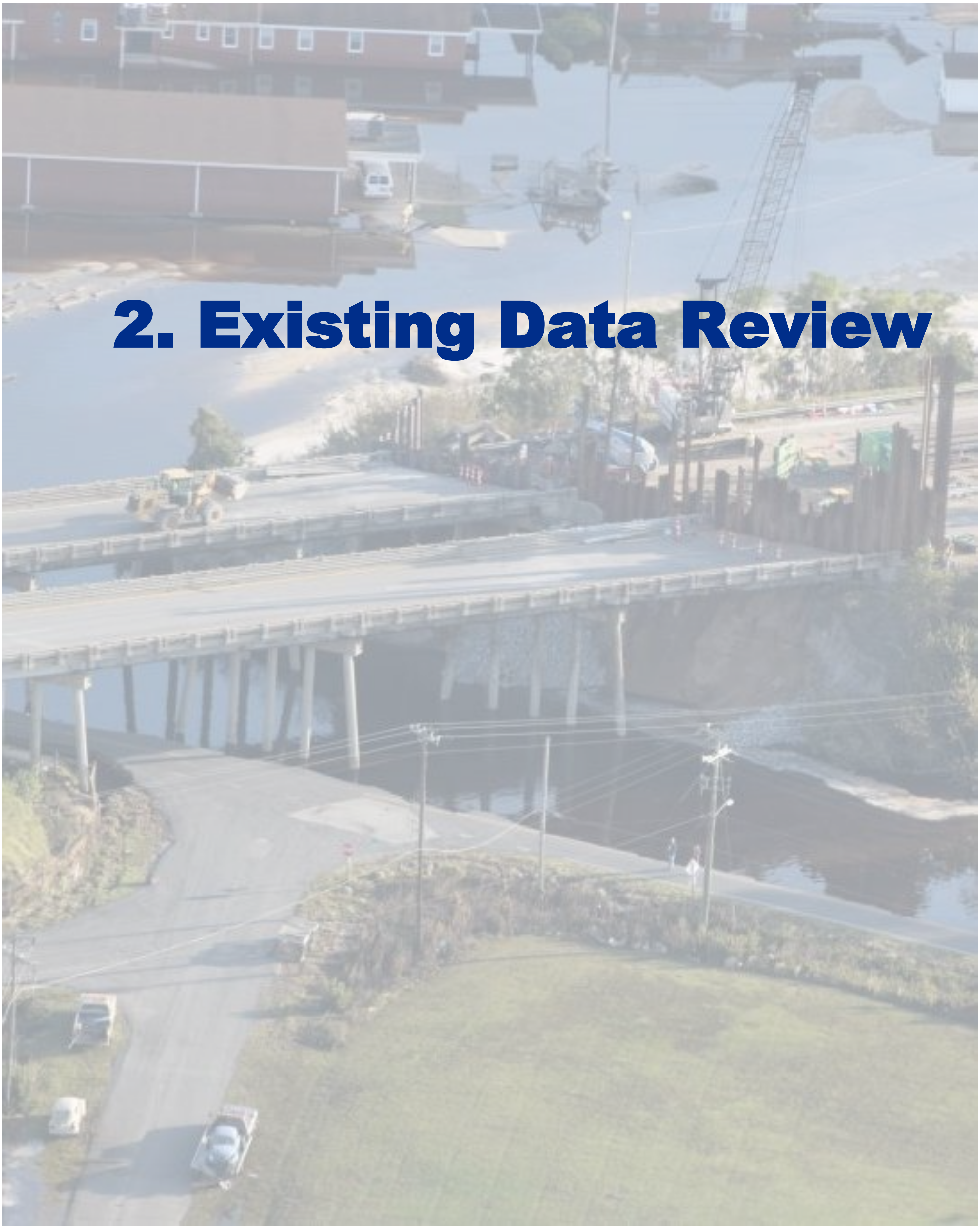
Figure 2: City Water Treatment Plant Flooded to Depths up to 4 Feet

Purpose of Study/Scope/Goals

The purpose of this document is to:

1. Establish the cause of the extensive flooding in the western and southern parts of the City of Lumberton;
2. Explore options to provide protection from future flooding events; and
3. Provide recommendations to assist in determining a solution that protects the community from damaging flooding, is cost effective, and offers ancillary benefits to the City of Lumberton.

2. Existing Data Review



2. Existing Data Review

Lumberton and the Jacob Swamp Watershed Improvement Plan

The Lumber River is a valuable asset to Robeson County and the City of Lumberton. It was designated as a National Wild and Scenic River at the federal level and was designated as a State park in 1989 due to its natural beauty and recreation value. The river also has a long history of flooding portions of Lumberton. In the early 1900s drainage districts were formed to help areas subject to flooding become inhabitable and usable for cropland. Significant flooding occurred in 1928, 1945, and 1964 resulting in road closures, crop and property damage, and displacements.

Following the 1964 flood, Robeson County Drainage District Number 1 and the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS), began working on the Jacob Swamp Watershed Improvement Plan. These improvements were intended to improve drainage in order to ease flooding concerns and prevent the frequent damaging floods, thereby opening up additional land for agriculture and other types of development. In the Jacob Swamp Watershed the existing stream channels for Jacob Swamp, Little Jacob Swamp, Gum Branch, and Cotton Mill Branch were widened and deepened. A maintenance plan was put into place to keep these channels and the immediate overbank area free of blockage. Additionally, and most significantly, in 1975 construction began on a levee along the Lumber River. The earthen dike was completed by the NRCS in 1977. It tied into I-95 to the north and extended approximately 2.8 miles to the south where it tied in with Alamac Road (SR 2289). A collection canal was constructed to facilitate the interior drainage of the area behind the levee. The collection canal flows north to south, connecting Cotton Mill Branch and Gum Branch to Jacob Swamp. All the runoff from the area protected by the levee is collected into Jacob Swamp and flows out of the levee-protected area through the bridge crossing on Alamac Road (SR 2289). The City accepted responsibility for the operation and maintenance of the levee as well as all drainage canals within the city limits. The Robeson County Drainage District is responsible for maintenance of the remaining canal reaches.

The North Carolina Floodplain Mapping Program (NCFMP) provided the original 1975 Levee Construction Drawings to AECOM for review. The drawings indicate that the earthen levee was designed with 3-horizontal to 1-vertical side slopes and a 10-foot wide crest. A 10-foot wide, 2-foot deep keyway into existing ground was constructed beneath the levee centerline. No internal drains (toe, chimney, etc.) were included in the design of the levee.

The drawings do not document the types of soil used to construct the earthen levee, but based on boring logs on the drawings, on-site soils range from sands to clays. Although it is assumed that the construction documents identified the most suitable soil types for levee construction, field exploration will be required to verify actual soil conditions.

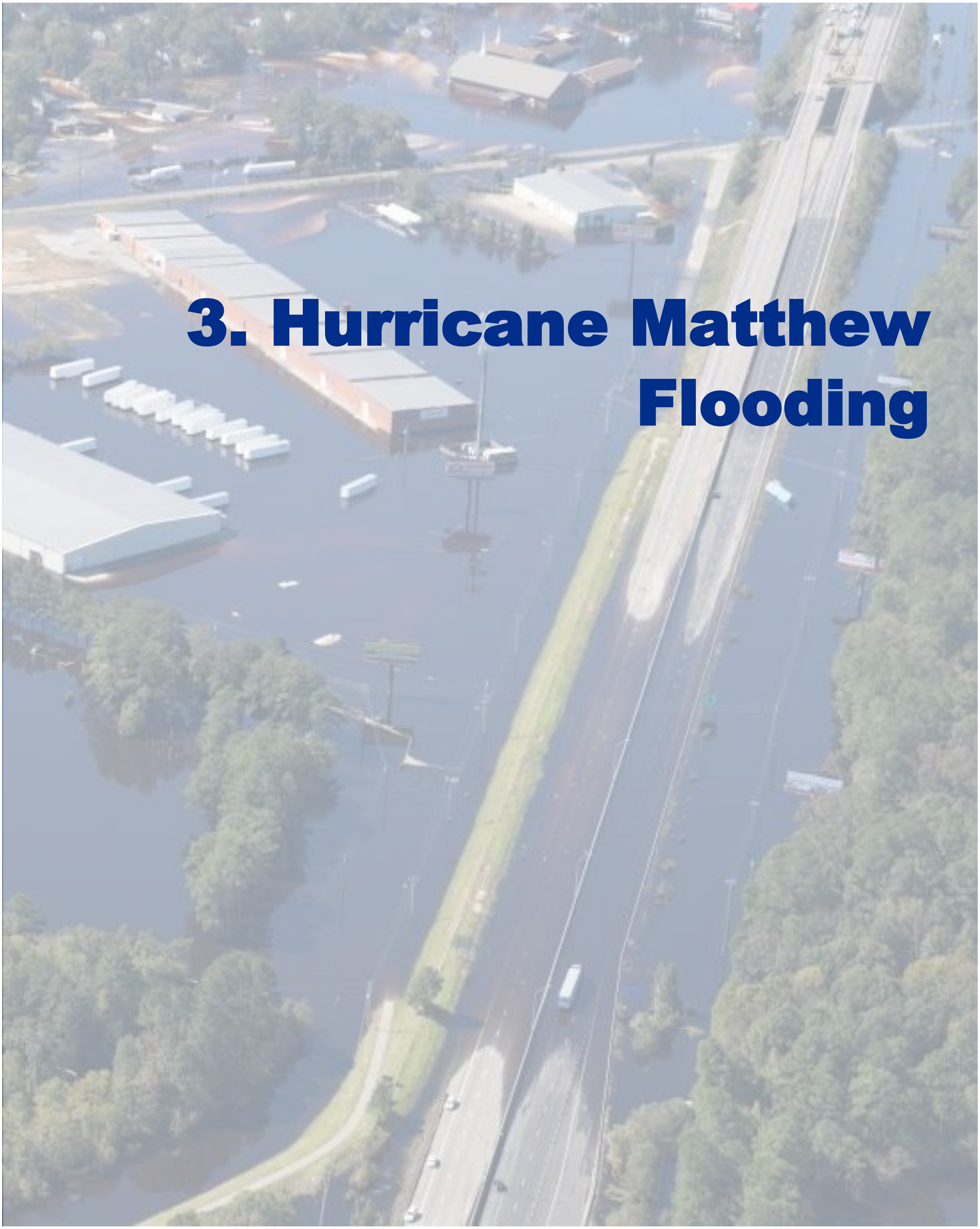
The exposed levee slopes are generally grass covered, although riprap has been placed on the river side slopes in selected areas. More details regarding the design of the levee can be found in Appendix D: Jacob Swamp Watershed Improvement Plan As-Built.

The original 1975 construction drawings indicate locations where test borings were conducted and list generic boring logs with depths and soil classifications. The drawings also include the design data and locations for drainage pipe crossings through the levee. Plan and profile sheets included in the Construction Drawings show locations of buried utility lines, including phone, water and sewer lines. Some of these utilities crossed the levee while others were located parallel to the river side or land side of the embankment toe of slope. Flap valves are in place to protect the inlet of two RCP drainage culverts running beneath the levee in the vicinity of I-95 and one at the West 5th Street crossing.

The original watershed improvement plan included provisions for closing the underpass at I-95 and VFW Road (SR 1541); however those plans were never completed. The road was to be raised from an elevation of 122.43' to of 124.53' and a 10-foot wide earthen dike was to have been constructed in the area between VFW road and the railroad. Agreements were reached between all parties but the permanent improvements were not made. As an alternative, agreements were signed for an emergency sandbagging plan that would interrupt traffic on VFW Road and the Railroad during a flood.

The levee was certified as providing flood protection for the 1% annual chance event by letter from the NRCS dated October 9, 1987 and was accredited by FEMA as providing protection on the 1993 Flood Insurance Rate Maps. On May 21, 2003 the decision to accredit the levee came into question by the NCFMP. In discussions with FEMA it was determined that the levee should not be considered to provide protection. This is due to the fact that the planned closure for the opening at VFW Road was not implemented and the alternate plan to sandbag the opening did not comply with the requirements of 44 CFR 65.10(b)(2) of the NFIP regulations which states "all openings must be provided with closure devices that are structural parts of the system". Original data relevant to the history of the Jacob Swamp Watershed can be found in Appendix H: Jacob Swamp Watershed Historical Data.

3. Hurricane Matthew Flooding



3. Hurricane Matthew Flooding Event

Event Description

On Saturday October 8, 2016 Hurricane Matthew made landfall near McClellanville, South Carolina and began moving up the coast of South Carolina and North Carolina. The tropical moisture provided by the storm interacted with a frontal boundary to produce extreme rainfall over the eastern Piedmont and Coastal Plain counties of North Carolina with some areas reporting as much as 18 inches of rainfall over a 36-hour period. Record rainfall totals were seen in 17 counties including Robeson, where the 12.53 inches recorded at Lumberton broke the previous record established by Hurricane Floyd of 7.62 inches. This is a significant rainfall event, approximately equal to the 0.2% annual chance rainfall event for Lumberton for a 24-hour rainfall event. The combination of the record rainfall and wet soil conditions due to a wet September resulted in record level flooding at many locations, including the Lumber River at Lumberton (USGS gage 02134170). Figure 3 shows rainfall for the Lumber River basin upstream of Lumberton.

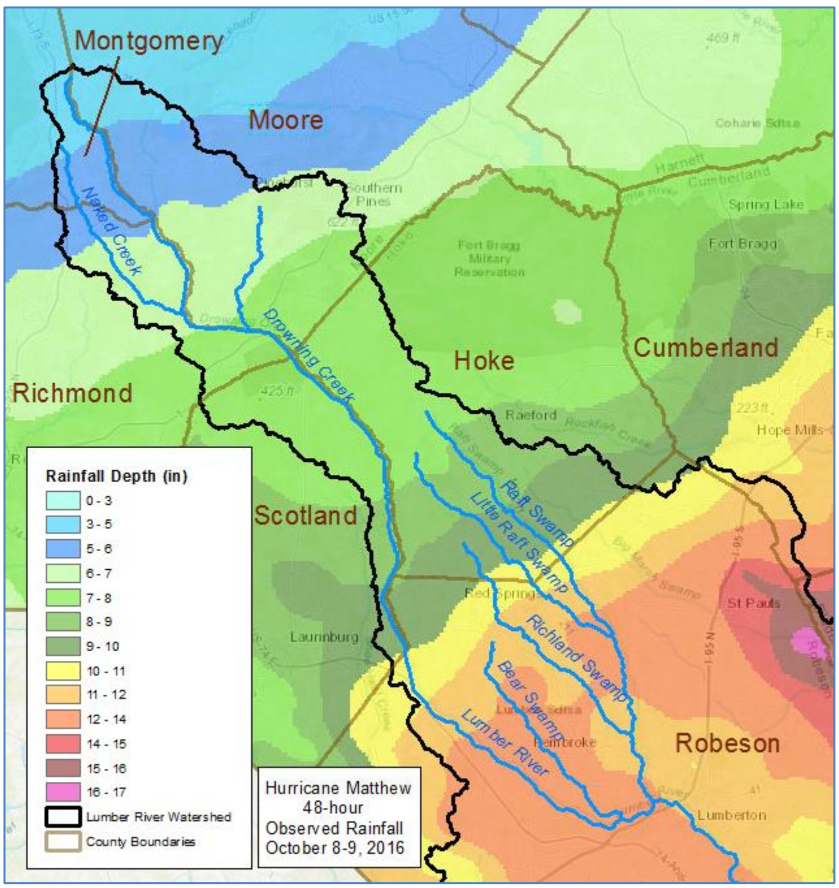


Figure 3: Rainfall Depths in Lumber River Basin Upstream of Lumberton

Riverine Flooding Summary

The USGS documented stream gage data in the report "Preliminary Peak Stage and Streamflow Data at Selected Stream gaging Stations in North Carolina and South Carolina for Flooding Following Hurricane Matthew, October 2016". Stream gage data from the Lumber River is shown in Table 2. Hurricane Matthew set records for both stage and discharge at all three gages by a wide margin. Figure 4 shows the location of the USGS gage in Lumberton.

Table 2. Lumber River USGS Stream gage Data

USGS Gage	River Name and Location	Drainage Area (sq mi)	Peak Matthew Stage (ft)	Previous Record (ft)	Peak Matthew Discharge (cfs)	Previous Record (cfs)	Years of Record
02133624	Lumber River near Maxton, NC	365	15.49	13.52	7,140	3,380	29
02134170	Lumber River at Lumberton, NC	708	21.87	18.29	14,400*	7,420	17
02134500	Lumber River at Boardman, NC	1,228	14.43	10.70	38,200	13,400	95

* Later revised to 14,600 cfs

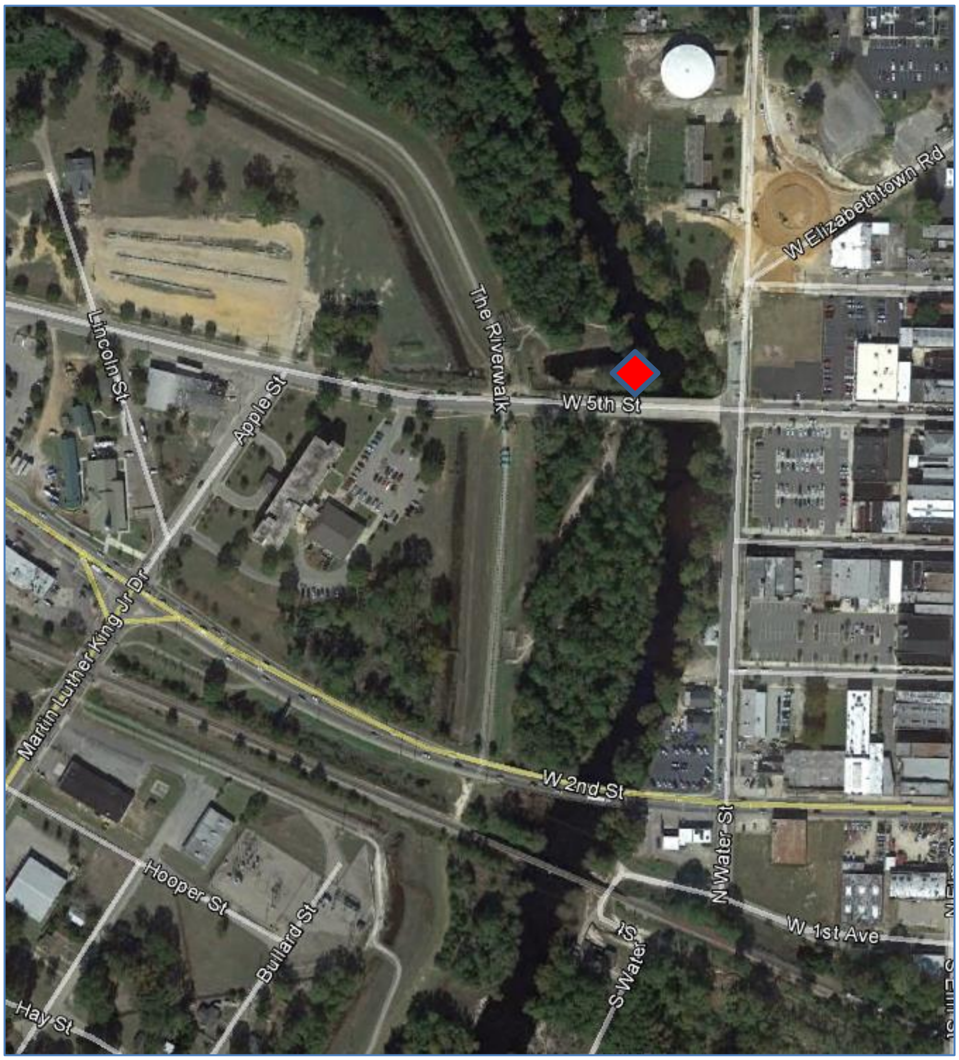


Figure 4: USGS Gage 02134170 – Lumber River at Lumberton

The Lumber River had been receding from a previous minor flood event that peaked in the early morning of October 5th at an elevation of 112.9’ and a flow of 3,100 cfs. The stream flow had fallen to an elevation of 110.5’, the lower limit of minor flooding, and a flow of 1,620 cfs at 3:30 in the morning of October 8th. The river level began to rise again in response to the initial rainfall from Hurricane Matthew at about 4 AM on the 8th and continued to rise steadily over the next 49.25 hours. The Lumber River reached the moderate flood level of 113.5 feet at 4:15 PM on the 8th and the major flood level of 114.5 feet 2.5 hours later at 6:45 on the 8th before peaking at 119.35 feet, almost 5 feet above major flood stage, at 4:45 AM on October 10th. The accompanying peak flow of 14,600 cfs was the maximum discharge recorded since the gage record began in 2001, and nearly twice the previously recorded maximum peak flow of 7,420 cfs that was recorded in September 2004.

The river remained above minor flood stage for more than 15 days, above moderate flood stage for almost 9 days and above major flood stage of 114.5 feet for almost 8 days. The Lumber River flow rate was in excess of 13,100 cfs, 90% of the peak flow of 14,600 cfs, for 46 hours. Figure 5 shows the extent of the flooding. For more information on stage and discharge hydrographs see Appendix A-Supporting Data.

Figure 5: Extent of Flooding in Lumberton due to Hurricane Matthew

Cause of Flooding in South and West Lumberton

In addition to the extreme rainfall in the area, the extensive flooding seen south of I-95 and west of the levee can be attributed to three factors:

- Conveyance through the opening at VFW Road underpass,
- Insufficient conveyance in the drainage canals; and
- Backwater from the Lumber River entering through the bridge at Jacob Swamp on Alamac Road (SR 2289).

Conveyance Through the Opening at VFW Road Underpass

At the time of construction of the levee, the NRCS estimated the 1% flood elevation on the Lumber River at the VFW Road opening to be 124.03' and estimated conveyance through the underpass at 740 cfs. During Hurricane Matthew, a sandbagging effort was made at the underpass but this failed at some time before dawn on October 10th and water began flowing into the City. A high water mark collected approximately 800 feet north of the opening indicates the elevation during Matthew may have been as high as 125.3 feet. A HEC-RAS model for the Lumber River was developed by ESP Associates for the NCFMP in 2013. This model is considered the best available hydraulic model for the Lumber River at this time. Figure 6 shows the preliminary HEC-RAS model for the Lumber River with profiles for the 1% and 0.2% annual chance flood events. The red targets indicate high water marks collected following Matthew. A water surface above elevation 125 would indicate a flow rate of perhaps 1,250 cfs through the railroad opening.

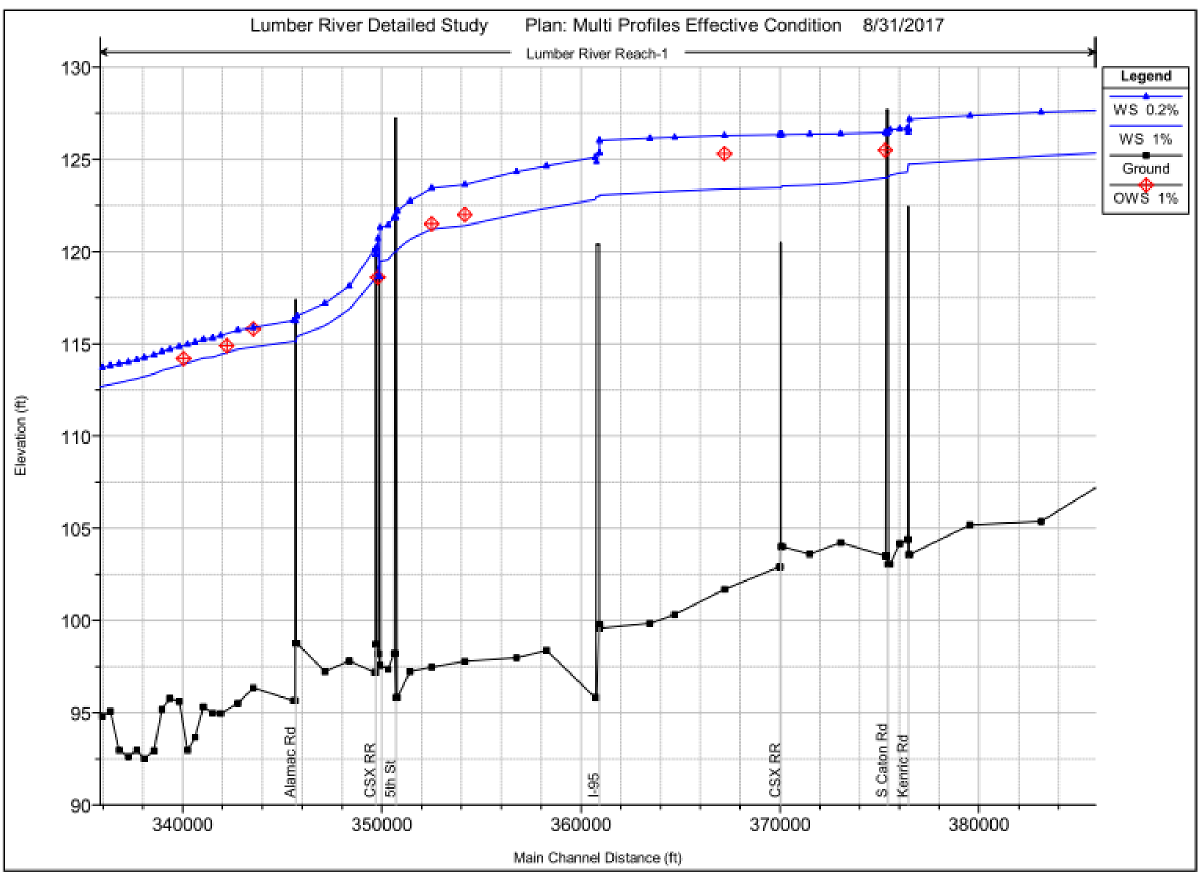


Figure 6: Lumber River Profile with Hurricane Matthew High Water Marks

A Trip Report developed following a field visit by the USACE on October 11, 2016 documents that significant flow from the Lumber River passed through the VFW Road underpass. This report is included as Appendix G: USACE Lumberton Trip Report – 20161011. Once the water overtopped the railroad, which is at an elevation of approximately 121.5', the floodwater went south through the railroad ditch to the low spot on VFW Road which is at an elevation of approximately 117.5'. The photo in Figure 7 below show water flowing south through the underpass at estimated velocity of between 6 and 8 feet per second and flooding areas to the west of the railroad and to the east of VFW Road. Figure 8 shows the scour that resulted from the high velocity flow. These photos were taken during the USACE field visit at approximately 1PM on October 11th, some 30 hours after the peak stage recorded at the USGS gage location at the upstream face of the 5th street crossing. During the dewatering process, NRCS estimated that considering the damage and scour at VFW Road and the railroad, water would continue to exit to the north under the VFW Road crossing until it reached an elevation of approximately 118', or about 7 feet below the recorded high water mark in the vicinity. As of October 13th, three days after the peak gage reading, water was still flowing across VFW Road.

Figure 7: Water flows south from VFW Road Underpass Washing Out Railroad and Overtopping VFW Road

Figure 8: I-95 Abutments Eroded on SW Side of Underpass. Railroad not Apparent

In Figure 9, imagery from 10/16/2016 shows deposits made by the rapidly flowing water as it passed under I-95, eroded the abutment, and made its way into the southern and western parts of the City.

Figure 9: Deposits Mark Path of Flow to South of Railroad and North of VFW Road

Using the conservative estimate of 740 cfs and assuming a sustained inflow of this magnitude for 30 hours, this is more than enough volume to inundate the area behind the levee to both the east and west of the railroad. The peak water surface between the levee and the railroad was approximately 119.8' which implies approximately 1,470 acre feet of water. This is volume is equivalent to a flow rate of 600 cfs for 30 hours or 250 cfs for 72 hours.

Condition of the Earthen Levee

Although significant damage to the roadway and railroad in the vicinity of the VFW Road underpass beneath I-95 occurred as a result of the flooding, damage to the earthen levee itself was not observed. In the October 11th USACE Trip Report, it is noted that no visual evidence of levee overtopping or levee distress was observed. At that time, flooding was present on both the land and river side of the levee and much of the slopes and the toe of the levee were not visible.

According to Mr. Rob Armstrong, Public Works Director, City of Lumberton, no damage to the levee was visible after floodwaters receded. No report documenting levee conditions after flooding was provided to AECOM.

AECOM staff, along with City of Lumberton staff and Thomas E. Langan of the NCFMP conducted a site visit on August 3, 2017. This site visit included a windshield and walking visual inspection of the levee from the crest. It is not considered to be a detailed engineering inspection of the earthen levee, but the purpose was for information gathering. At the time of the site visit, the levee appeared to be well maintained and grass covered. Much of the crest was paved with asphalt and used as a public walking trail. There was no evidence of slope distress, subsidence or cracking at the crest. Standing water was observed in some locations near the land side toe of slope. This standing water was confined to the excavated drainage swales that are designed to collect and transmit land side stormwater runoff.

Based upon available information, it can be concluded that neither the crest elevation nor the structural condition of the levee contributed to the flooding experienced on October 8, 2016. The effectiveness of the flap valves protecting several drainage culverts crossing beneath the levees could not be determined since they were submerged during the event.

The information above supports the conclusion that the flooding experienced in the Lumberton area was a direct result of the failure to achieve closure at the VFW Road underpass.

Insufficient Conveyance in the Drainage Canals

Estimates indicate more than a foot of rain fell across the Lumberton area starting in the evening of October 7th and continuing throughout the day on October 8th. This is a significant rainfall, approximately equal to the 0.2% annual chance rainfall event. Rainfall of this magnitude would generally cause flash flooding and potentially impact structures as local drainage systems are overwhelmed. The drainage canals constructed by the NRCS were designed to convey the 1% annual chance event computed with rural regression equations and under optimal conditions. It is assumed that the majority of this rainfall was able to make its way to the drainage canals and begin to exit the project area prior to the Lumber River reaching peak stage on October 10th, but it is likely that the rainfall and insufficient conveyance resulted in some amount of localized flooding.

Lumber River Backwater

The primary drainage mechanism for local flooding for the area behind the levee is the bridge on Alamac Road (SR 2289) at Jacob Swamp. Based on the preliminary HEC-RAS model for the Lumber River, the backwater elevation for the river at the bridge during the 1% annual chance event flood is approximately 112.85'. Figure 10 shows the area that would be inundated based on the backwater from the Lumber River at this elevation.

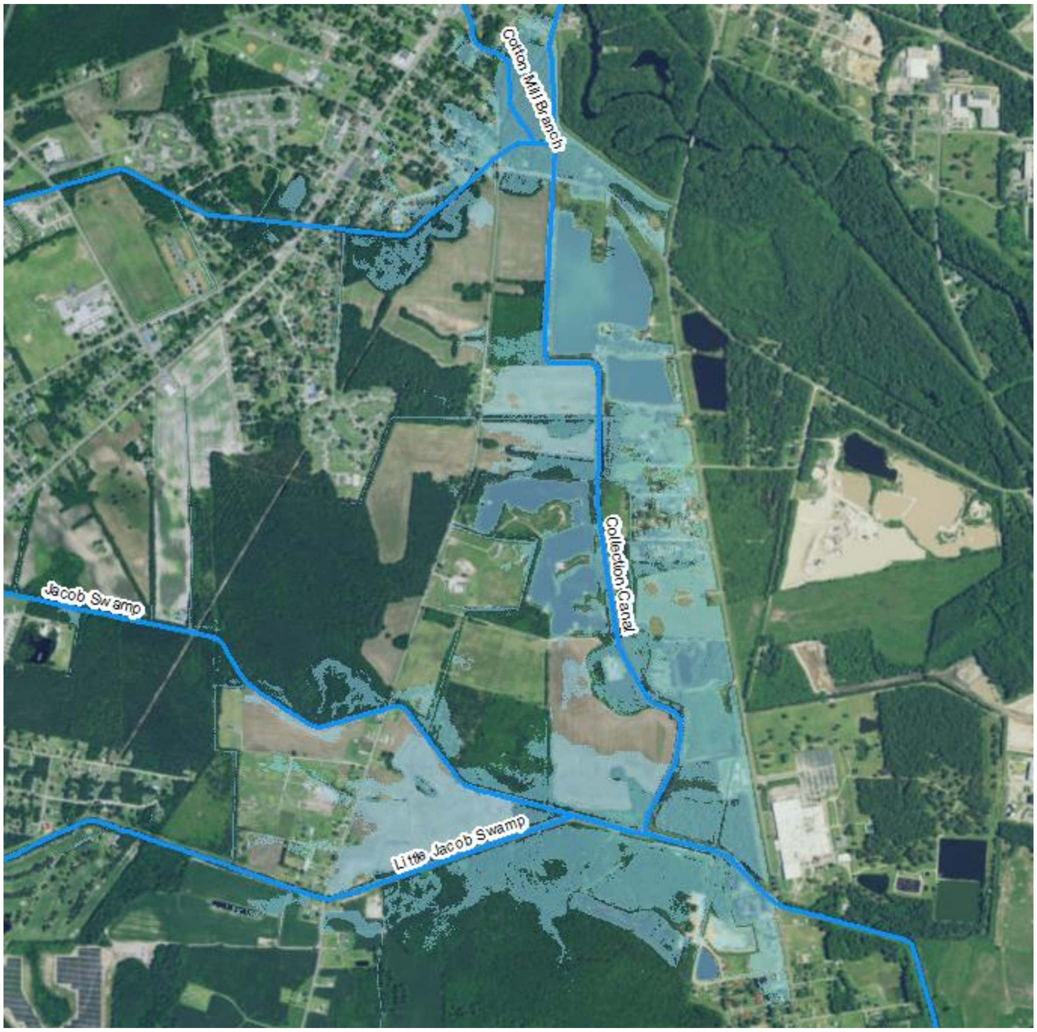


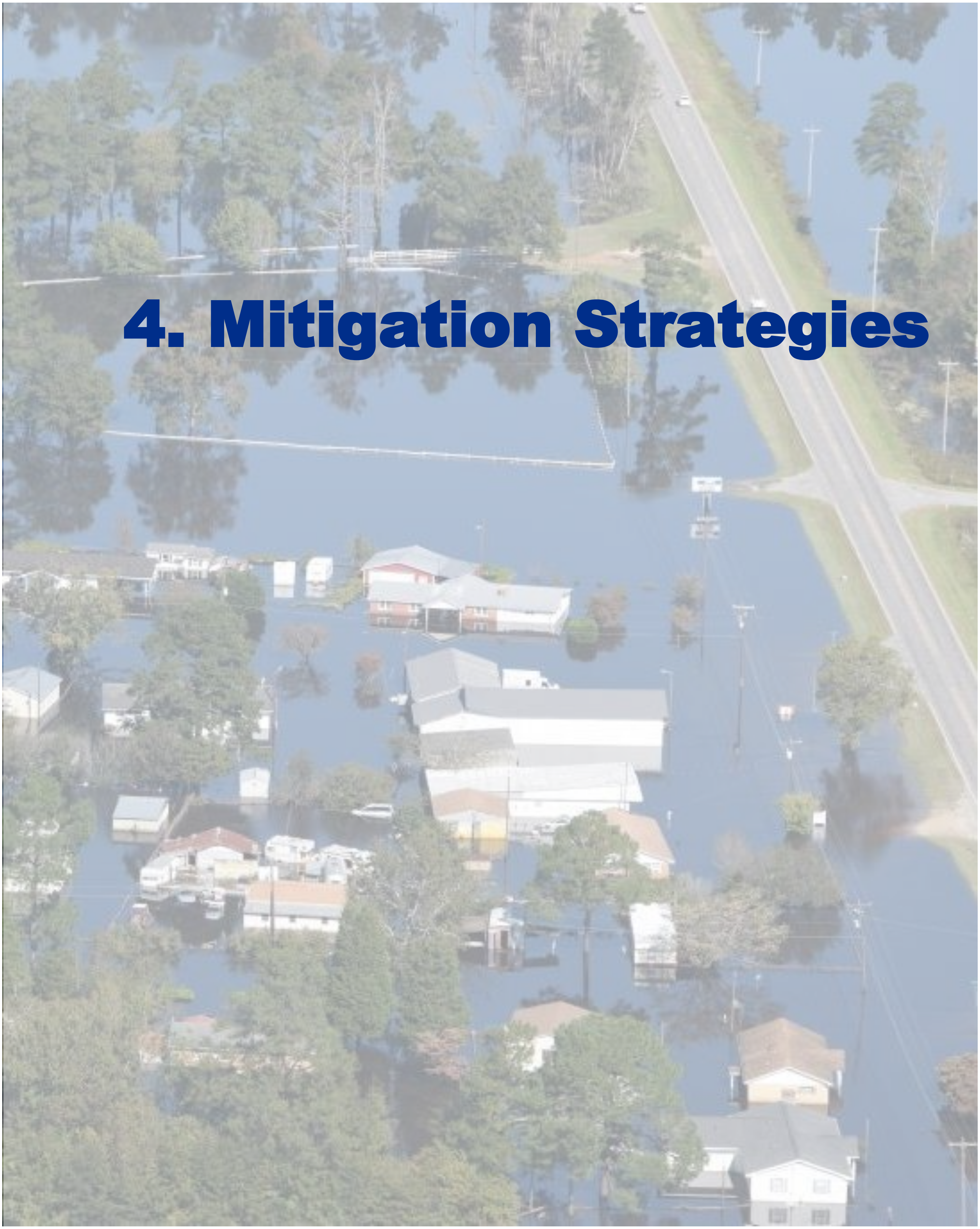
Figure 10: Inundation Potential from Lumber River Backwater at Jacob Swamp Bridge (SR 2289)

During a 1% annual chance event flood, backwater from the Lumber River alone has the potential to impact approximately 66 structures, all of which are classified as residential. Under ideal circumstances, the local drainage canals will have passed their peak flood stage by the time the Lumber River approaches its crest. However, if the interior drainage system is taking on water from another source, such as flow through the VFW Road underpass at I-95, the Lumber River backwater will significantly reduce the conveyance in the already undersized drainage canals. The result will be significant flooding throughout the Jacob Swamp watershed as it takes on water from the underpass and at the same time is unable to effectively drain. Water surface elevations above 115' were reported near the outlet under Alamac Road.

Flooding Event Summary

The flooding experienced in Lumberton area had several contributing factors, but the overriding factor that caused the majority of the devastation was the failure to have a proper closure at the VFW Road underpass. The following section outlines some mitigation alternatives to consider in order to reduce future flooding impacts.

4. Mitigation Strategies



4. Mitigation Strategies

If no mitigation strategies are implemented, the first point of failure in the levee system protecting the project area will be the underpass at VFW Road. During a flooding event similar to Matthew, water will overtop the railroad at an elevation of approximately 121.5'. This is equivalent to an event with an estimated recurrence interval of between 25 and 50 years based on the preliminary HEC-RAS model for the Lumber River. This assumes that sandbagging of the ditch to the west of the railroad will occur and be successful and that no sandbagging will occur above the grade of the railroad. If a closure device is put into place at the underpass, the next point of failure would be overtopping of I-95 at a location approximately 3,500 feet west of the VFW Road underpass. Based on available Light Detection and Ranging (LiDAR) data and original design plans from NCDOT, the highway appears to be very close to the base flood elevation of 123.6' in the preliminary HEC-RAS model. This area did not overtop during Hurricane Matthew and it is recommended that more detailed survey be acquired.

Hydrologic Uncertainty

Much of the discussion on mitigation options is based on the 1% annual chance flood event. It is important to note that there is an amount of uncertainty in the true 1% discharge value. An updated gage analysis which included the 14,600 cfs estimate for the Matthew event was performed on the USGS gage at 5th Street in Lumberton. This analysis is included as Appendix J – Lumber River Gages PeakFQ. In order to improve results of the analysis, the gage record was extended using data from the downstream gage at Boardman which has 95 years of record. While this gage extension process was helpful to refine the discharge estimates, the reader should be aware of the confidence level of this estimate if it is to be used as the 1% flood for design purposes. In Table 3, the discharge ranges are shown for the standard error and the 90% confidence interval. The standard error can be considered as the standard deviation of the sampling distribution. As the sample size, in this case observed annual discharge peaks, increases, the amount of uncertainty and therefore the standard error will shrink. The 90% confidence interval is an upper and lower bound for which there is a 90% chance that the true discharge value is within these bounding values. This means that statistically there is a 95% chance that the true 1% discharge is less than the upper bound. Similarly, there is a 95% chance that it is greater than the lower bound.

Table 3: Uncertainty Analysis for USGS 02134170 – Lumber River at Lumberton, NC

Percent Annual Chance Flood	Computed 1% Annual Chance Discharge (cfs)	Standard Error (cfs)	90% Confidence Interval (cfs)
10%	7,720	6,420 – 9,790	5,780 – 12,000
4%	10,200	8,200 - 13,600	7,280 – 17,600
2%	12,300	9,630 – 17,000	8,460 – 22,800
1%	14,500	11,100 – 20,800	9,620 – 28,800
0.2%	20,100	14,700 – 31,300	14,700 – 46,500

Using the upper value for the standard error analysis, the VFW Road underpass would have a greater than 4% chance of flooding during any given year and I-95 would have a greater than 2% chance of being overtopped. During the 1% annual chance flood, the levee would be breached at 5th street and would maintain less than 2 feet of freeboard at all other locations.

Strategy 1 – Installation of Flood Gate at VFW Road and Railroad Underpass

Lumberton levee enhancements are listed as the number 2 priority for the county in the RRP. To achieve closure at the VFW Road underpass, a closure gate should be installed.

The recommended primary gate design would be a swing gate with the width of the gate exceeding the roadway crossing by a minimum of 2 feet clear on each side. The concrete monolith that houses the gate would be pile founded. Swing gates are preferred since they can be easily closed by a two-person field crew. A mechanized swing gate would be designed for the location at the underpass of I-95 and VFW Road. Railroad clearances would comply with American Railway Engineering and Maintenance-of-way Association (AREMA) criteria. Figure 11 shows a conceptual view of what these gates may look like at the VFW Road and Railroad closure site. Example technical sketches can be found in Appendix B: Flood Gate Concept.

Figure 11: View of Flood Gate from VFW Road Looking North Toward I-95

- **Driven Foundation Piles:** Pilings would be driven steel H-pilings. The size and batter would be selected with consideration given to loading conditions, computed displacements, both differential and vertical, space, and real estate boundary limitations, vibrations, cost, and effects of installation on operations. Where settlement is considerable measures would be taken to design the piles to resist downdrag forces. The ready solution is to preload the foundation footprint adding wick drains as needed to reduce the preload duration.

  H-Piles would be Grade 50 steel and considered where the rock formation is greater than 50 feet below the surface. Piles would be driven on an approximate 1H on 3V batter to more efficiently resist the lateral hydrostatic loads. Typical pile configuration is shown in Figure 12.

Figure 12: H-piles With Batter and Tension Hooks

- **Seepage Cut-off Wall:** A sheet pile cutoff wall would need to be driven to the bottom of the sheet pile to minimize seepage and prevent piping. Until the final geotechnical borings are complete, it is assumed that the sheet pile would be 20 feet deep. The top of piling would be embedded 6”-9” into the wall base. Figure 13 shows a typical sheet pile cutoff wall.

Figure 13: Typical Seepage Cutoff Wall

- **Utility Penetrations Through Floodwalls:** When possible, utility lines should penetrate floodwalls above the foundation to facilitate replacement or maintenance in the future. Lines can pass above or below the T-Wall base, but must be passed through a water tight sleeve. Gravity lines, such as storm drainage systems, would include a positive shut off valve and when necessary a flap, duck or backup prevention device. Figure 14 shows a typical utility penetration.

Figure 14: Typical Utility Penetration

- **Technical Guidance:** Industry codes and standards exist in a number of sources and additional technical guidance is available in multiple USACE publications. A listing of these is included in Appendix A: Supporting Data.

- **Operations and Maintenance Manual and Agreement between Parties:** An operations and maintenance manual would be developed during design. The operation plan would meet the NFIP Regulations paragraph 65.10(c)(1), Operation Plan. The maintenance plan would meet the NFIP Regulations paragraph 65.10(d), Maintenance Plan. Key elements of these regulations can be found in Appendix A: Supporting Data.

- **Emergency Closure and Action Plan:** During design, an emergency closure and action plan would be written outlining the timing and procedures of when to close the floodgates. The USACE provides a guide book for developing the Emergency Action Plan. Reference information on this is included in Appendix A: Supporting Data.

- **Interim Solutions:** In order to provide the community with immediate protection pending construction of a flood gate, it is recommended that temporary flood protection, such as HESCO baskets or similar products, be on standby and deployed in advance of a high water event. These would also be used for as protection during construction. Temporary drainage pumps and required fuel would be staged near West 2nd St. adjacent to the levee. Cost for HESCO product type protection is approximately $35 per linear foot for a protection height of 4 feet. Fill material, such as sand, would need to be maintained in close proximity. Figure 15 shows a 3'x4'x15' HESCO unit.

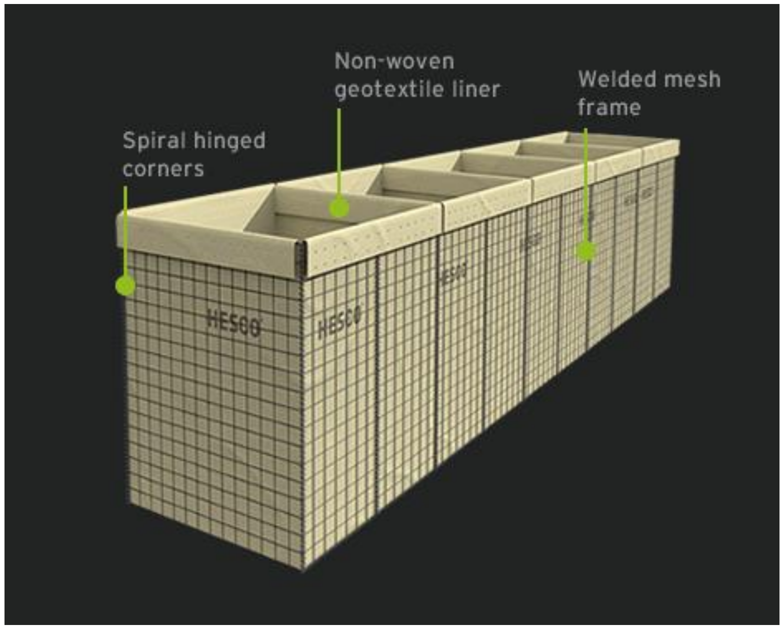


Figure 15: HESCO Floodline Bastion

A hypothetical HESCO configuration for the VFW Road underpass can be found in Appendix I.

- **Strategy Costs:** Estimated costs in Table 4 do not include pricing of the piles which needs to be determined during the detailed design phase.

Table 4: Estimated Costs for Strategy 1 – Installation of Flood Gate at VFW Road Underpass

Description	Units	Unit Rate	Quantity	Item Cost
T-Wall Base	Cubic Yard	$500	110	$55,000
T-wall Stem	Cubic Yard	$800	65	$52,000
Railroad Gate	Lump Sum	$72,000	1	$72,000
Railroad Gate Seal	Lump Sum	$5,500	1	$5,500
Railroad Gate Monolith	Cubic Yard	$600	65	$39,000
Highway Gate	Lump Sum	$80,000	1	$80,000
Highway Gate Seal	Lump Sum	$5,700	1	$5,700
Highway Gate Monolith	Cubic Yard	$600	100	$60,000
Bollards	Each	$600	2	$1,200
36" Pipe	Linar Feet	$150	20	$3,000
Sluice Valve	Each	$12,000	1	$12,000
Concrete Slope Protection	Cubic Yard	$300	275	$82,500
Sheet Pile	Square Foot	$40	465	$18,600
				$486,500

- **Losses Avoided and Return on Investment:** It is assumed for this strategy that the levee would perform as it did during the Hurricane Matthew event, therefore any structure flooding with the flood gate in place would be the result of flooding on the interior drainage channels. The effective modeling and effective floodplain boundaries acquired from North Carolina Emergency Management (NCEM) reflect flooding on the interior drainage channels and were therefore used for damage assessments. It is strongly recommended that these effective studies be revisited due to revisions to hydrologic methods and improved terrain data. Costs to the residents for annual flood insurance premiums are not included. The losses avoided calculation in Table 5 is based on losses avoided during the 1% annual chance flood event only. Direct losses include estimates of losses based on structural damage and loss of property and contents. Indirect losses include estimates for relocation costs, lost income and wages, lost sales, and lost rent.

Table 5: Preliminary Losses Avoided/Cost for Strategy 1

Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
$486,500	$ 1,913,049	$ 3,453,755	3.93	11.0

Strategy 2 – Enhancements to Levee and Accreditation of Levee System

As noted in Strategy 1, levee enhancements are a high priority for Robeson County and the City of Lumberton. As discussed previously, the earthen levee apparently suffered no structural distress associated with the flooding event on October 2016. The levee, as currently constructed, did not overtop or fail during the flooding or once the flood waters receded. The earthen levee, as it currently exists, appears to be well maintained and only routine maintenance and upkeep is required.

It appears feasible to complete modifications to the levee to meet the requirements of 44 CFR 65.10 of the NFIP Regulations and to result in certification by a licensed professional engineer showing that the levee system is expected to provide 1-percent-annual-chance (base) flood risk reduction.

Modifications required to bring the levee system in compliance with 44 CFR 65.10 can be broken into the following categories:

- Freeboard
- Closures
- Embankment Protection
- Embankment and Foundation Stability Analyses
- Settlement Analyses
- Interior Drainage
- Operations Plan
- Maintenance Plan

A summary of the levee conditions and required modifications are provided in the subsequent sections.

- **Freeboard:** The minimum freeboard required is 3-ft above the Base Flood Elevation (BFE) with an additional 1-ft in the vicinity of structures and an additional 0.5-ft at the upstream end of the levee. While the Lumberton levee did not overtop during Hurricane Matthew, current survey data indicate that the crest elevation of the levee is deficient in several locations compared with the required freeboard based on the preliminary HEC-RAS model. These areas are summarized in Table 6 below, although the existing crest elevation and the actual extents of required improvements need to be verified during the investigation phase. Figure 16 identifies the 6 locations highlighted below from plan view.

Table 6: Summary of Freeboard Deficiencies based upon Preliminary Data

Location	End Station	Freeboard Deficiency (FT)	Description	Potential Mitigation
#1	0+00 to 42+00	1-3	Levee crest adjacent to northbound I-95	Raise levee using earthen embankment or flood wall
#2	54+00 to 56+00	1-7	CSX Railroad and VFW Road	Construct closure
#3	66+00 to 85+00	1-3		Raise levee using earthen embankment or flood wall
#4	85+00 to 91+50	1-2		Raise levee using earthen embankment or flood wall
#5	141+50 to 143+25	1-3	W. 5th Street Crossing	Provide closure, raise roadway (bridge replacement may be required)
#6	219+00 to Terminus	1-2	Alamac Road	Raise levee using earthen embankment

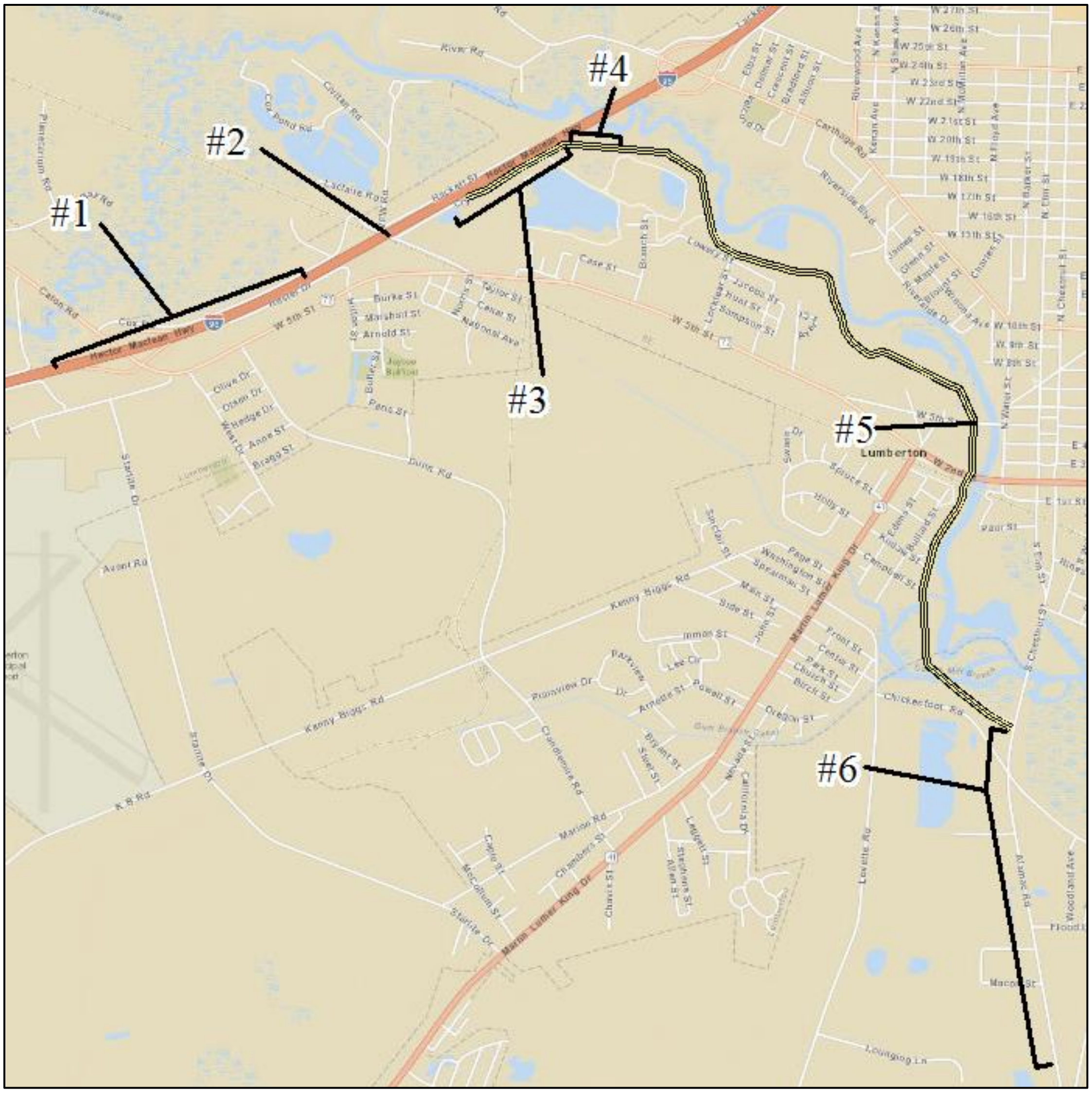


Figure 16: Areas of Freeboard Deficiency

Additional detail on locations of potential freeboard deficiencies can be found in Appendix C: Levee Plan and Profile. Stationing in Table 6 references Appendix C.

The most critical improvement is the closure at the CSX railroad and VFW Road. Raising the levee crest to the required elevation could be accomplished with a levee raise (land side raise is preferred, but feasibility to be determined during design phase) or by constructing a floodwall such as a concrete or sheet pile structure.

- **Closures:** The most critical area requiring closure is located at the CSX railroad and VFW Road underpass at I-95. The solution for this closure would be a flood gate as detailed in the discussion above. The freeboard deficiency where West 5th Street crosses the levee can be mitigated by installing a closure on the north and south sides of the crossing. Alternatively, the roadway can be raised to meet the required freeboard. This may impact the existing 5th Street bridge over the Lumber River and should be evaluated in more detail during the design phase.
- **Embankment Protection:** Limited embankment protection (in the form of riprap) is currently in place on the levee slopes. An assessment of the potential scour velocities should be included in the design phase.

This will determine the need for slope protection, especially near structures and adjacent to drainage ditches.

- **Embankment and Foundation Stability Analyses:** No record of detailed analyses of the stability of the levee or levee foundation is available. In order to obtain engineering certification of the levee, a Geotechnical investigation, laboratory testing, and analyses will be required as outlined in guidance issued by the U.S. Army Corps of Engineers (Engineer Manual 1110–2–1913, *Design and Construction of Levees*). The USACE guidance addresses the following items pertinent to the Lumberton levee:
  - Subsurface Investigation,
  - Field Testing,
  - Laboratory Testing,
  - Foundation Seepage,
  - Embankment Seepage,
  - Slope Stability, and
  - Pipelines and Other Utility Crossings

  A subsurface investigation will be required in order to analyze and certify the levee. It is assumed that Geotechnical borings and associated field testing will be required on a nominal spacing of 500-ft along the levee alignment, including closures. Existing subsurface information will be considered when establishing the exploration program but will be of limited value since no detailed logs are available and the borings completed prior to construction were not drilled through the levee. Collection of representative soil samples is included in the exploratory program. Split spoon or thin walled tube samples will be sent to a Geotechnical testing laboratory to identify engineering properties of embankment and foundation soils, including:
  - Shear Strength,
  - Hydraulic Conductivity,
  - Compressibility/Consolidation, and
  - Classification

  Data from these laboratory tests will be used to establish and conduct slope stability models under the range of conditions found during the exploration and anticipated during flooding events. The analyses and related report forms critical information to the levee certification.

  Utility crossings beneath or through the earthen levee are critical to the performance of the levee during flood events. Structures such as flap valves must operate within program criteria to prevent bypass flooding. Underground utilities such as water lines, sewer lines and gas lines can impact the performance of the levee if they cross the levee or run adjacent to the toe of the embankment slopes. Failure of pressurized lines during or after a flood event could result in excessive earthen levee erosion and potentially failure of the levee. Each utility crossing must be evaluated and mitigation options addressed as part of levee certification. Mitigation could include re-routing, replacement, installation of control devices (valves, etc.) double containment or concrete encasement.

The Lumberton levee has numerous pressure lines (water and sewer) crossing the levee alignment. In addition, pressurized water lines are in place parallel to the toe of land side and water side slopes. Some of these lines were in place before the levee was constructed and are presumed to run through the foundation. New water lines connecting water supply wells to the water treatment plant adjacent to the levee were reportedly constructed after the levee was completed. No records of the water line construction have been made available to AECOM and it is presumed that these were installed within the levee.

As part of certification, assessment of utilities determined to have potential impact on the levee performance will be completed. Cooperation with the City of Lumberton is essential in identifying and reviewing any as-built information on utilities and in locating the utilities in the field using non-destructive methods. Recommendations on mitigation options will be provided.

- **Settlement Analyses:** Based upon available as-built drawings, settlement was considered in the design, although no record of detailed analyses of the settlement of the levee or levee foundation is available. In order to obtain engineering certification of the levee, such analyses are required as outlined in guidance issued by the U.S. Army Corps of Engineers (Engineer Manual 1110–2–1913, *Design and Construction of Levees*). Although the levee has been in place for several decades and the risk of further levee or foundation settlement are low, analyses are required to document existing conditions as well as to evaluate future improvements, such as levee raises, closure structures and utility replacement.
- **Interior Drainage:** The primary vehicle for interior drainage is a constructed canal that runs roughly parallel to the levee and is referred to as the Collection Canal. The size of the canal varies from a 10 foot bottom width near the upstream of the levee to 20 feet downstream of the confluence with Gum Branch. An outlet structure consisting of a 42" RCP is located at the upstream face of the 5th Street crossing. This outlet is protected on the river side by a flap gate and will help reduce conveyance requirements on the landward side of the levee if functioning properly. Based on preliminary analysis, the Collection Canal appears to not have sufficient conveyance capacity to fully contain the 1% annual chance event. A more detailed analysis of the hydrology in the area and acquisition of field survey will be required for a full assessment. More discussion of interior drainage can be found in the section below focusing on interior drainage improvements.
- **Operations Plan:** As part of the design and analyses of any improvements to the levee system, an Operations Plan will be developed to document the steps required to routinely operate the system components. This Plan will require the cooperation of City, State, and Federal staff, CSX railroad, and other organizations impacted by closures and levee related emergency activities during flood events.
- **Maintenance Plan:** Requirements for the maintenance of the levee system will be outlined, including routine maintenance, repairs, new crossings, etc.
- **Strategy Costs:** Table 7 provides a rough order of magnitude estimate for levee certification.

Table 7: Estimated Costs for Strategy 2 – Levee Certification

Description	Units	Unit Rate	Quantity	Item Cost
Investigation	Lump Sum	$ 100,000	1	$ 100,000
Engineering Analysis	Lump Sum	$ 150,000	1	$ 150,000
Site Preparation	Lump Sum	$ 200,000	1	$ 200,000
Culvert Inspection	Lump Sum	$ 100,000	1	$ 100,000
Utility Location	Lump Sum	$ 60,000	1	$ 60,000
Levee Raise	Linear Feet	$ 500	800	$ 400,000
West 5th St. Improvements	Lump Sum	$ 1,500,000	1	$ 1,500,000
Water Line Improvements	Linear Feet	$ 200	1000	$ 200,000
Sewer Line Improvements	Linear Feet	$ 150	300	$ 45,000
Misc. Utility Improvements	Lump Sum	$ 250,000	1	$ 250,000
VFW Road Closure	Lump Sum	$ 486,500	1	$ 486,500
Riverview Park Restoration	Lump Sum	$ 200,000	1	$ 200,000
				$ 3,441,500

This estimate assumes NCDOT moves forward with an improvement project to widen I-95 and increase to road bed elevation to BFE +3'. This would achieve BFE requirements for levee certification for I-95 as well as prevent closure of a critical transportation link during a flood event emergency. If the interstate improvement project is not funded it would be necessary to either fund a floodwall structure on I-95 at a cost in excess of $1,000 per linear foot, or a new section of levee would need to be constructed outside of the I-95 right of way. These protection measures would need to extend southwest from the VFW Road underpass for possibly in excess of 2 miles. Additional survey data would need to be gathered to assess.

- **Losses Avoided and Return on Investment:** Under this strategy, the flooding that occurs on the landward side of the levee will be a result of flooding from interior drainage channels. The effective studies on interior drainage canals provided by NCEM were used in this analysis and, as noted above, these studies should be revisited. The costs for annual flood insurance premiums are not included. Elimination of these insurance requirements for federally backed loans would be a significant benefit to a traditionally economically disadvantaged community. Table 8 shows the Benefit/Cost for levee certification and accreditation.

Table 8: Preliminary Losses Avoided/Cost for Strategy 2

Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
$3,441,500	$ 1,913,049	$ 3,453,755	0.56	1.56

Strategy 3 – Improvements to Interior Drainage Channels

Strategy 3 involves widening the existing channels that were constructed by the NRCS and upgrading bridges and culverts along these channels as appropriate.

- **Channel Design:** The 1966 Jacob Swamp Watershed Improvement Plan included provisions for improvements to the existing drainage channels in the project area. The residents requested assistance from the County, City, and the NRCS to reduce flooding from Jacob Swamp and its tributaries. The plan received authorization and funding from congress and the NRCS completed design and construction of the channel improvements in September 1974. The project included Jacob Swamp, Little Jacob Swamp, Gum Branch, and Cotton Mill Branch as well as the levee and associated drainage canal known as the Collection Canal. The channels for Cotton Mill Branch, Gum Branch, and the upper end of the Collection Canal were designed to contain the runoff from a 1% annual chance 24-hour rainfall event. The lower portion of the Collection Canal as well as Jacob Swamp and Little Jacob Swamp were designed to hold the discharge from the above named tributaries plus the 10% annual chance event runoff from other sources. Following construction, operation and maintenance of the channel improvement measures were turned over to the City of Lumberton (for areas within the city limits) and Robeson County Drainage District #1.
- **Deficiencies:** The Robeson County RRP lists Jacob Swamp Watershed Plan Restoration as the third overall ranked priority for the County. It states that the desire of the community is to make improvements to the channels and structure crossings to restore 1% flood protection to the project area. Based on the as-built channel data and available LiDAR returns, the channels seem to be maintaining the designed dimensions. Documents associated with the 2005 FIS study in Robeson County note that structure crossings were not built as designed in the original NRCS watershed plan with the structure capacities being less than the design. This would have an impact on channel conveyance. Additionally, the report states that at the time of the field visit in 2003 the channels were not maintained in such a way as to meet the NRCS design for Manning's n-value roughness coefficients. This field visit was just a snapshot and there are supporting documents showing that there is an active maintenance effort for the channels. Additional details on channel and crossing dimensions can be found in Appendix A.

  The NRCS channel design was based on best available methods of calculation at the time and did not take into account future development and associated increased runoff. Rough hydrologic evaluations performed during this study using recently published regression equations found that the interior drainage canals, on average, need to have conveyance capacity increased by a factor of 2.5 in order to contain the 1% annual chance flood event discharges. Little Jacob Swamp appears to be the most undersized channel with a design capacity of 260 cfs. Using current rural regression equations and the NRCS computed drainage area, the peak discharge during a 10% annual chance flood event is 550 cfs. The hydrologic analysis performed for this study can be found in Appendix F: Interior Drainage Hydrology.

  Due to the potential for ponding and uncontained flow in the overbanks and between flooding sources, more detailed hydrologic and hydraulic modeling is recommended including a 2D hydraulic model and either a rainfall runoff hydrologic model or a rain on grid solution. There have not been extensive problems with flooding reported since the channels were constructed by the NRCS so it is possible that the hydrologic analysis found in Appendix F is overestimating the peak discharges in the channels.

A rough estimate based on NRCS design plans and the hydrologic analysis in Appendix F shows approximately 620,000 cubic yards of excavation would be needed for these canals to fully contain the 1% annual chance flood. This estimate includes approximately 150,000 cubic yards for the northern channels originally designed for the 1% annual chance event (Collection Canal/Drainage Ditch, Cotton Mill Branch, and Gum Branch) and approximately 470,000 cubic yards for the southern channels originally designed for the 10% annual chance event (Jacob Swamp, Little Jacob Swamp, and Jacob Swamp Diversion).

Depending on which reaches are improved, up to 26 road crossings may require upgrades to larger culverts or bridges with 13 of those on the northern channels.

- **Strategy Costs:** Table 9 below shows estimated costs for mitigation strategy 3. These cost estimates could potentially be reduced substantially following the conclusion of the recommended engineering analysis.

Table 9: Estimated Costs for Strategy 3 – Interior Drainage Improvements

Description	Units	Unit Rate	Quantity	Item Cost
VFW Road Closure	Lump Sum	$ 486,500	1	$ 486,500
Northern Channels				
Revised Engineering 2D	Sq. Mi.	$ 12,500	5.5	$ 68,750
Excavation	Cubic Yard	$ 5	150,000	$ 750,000
Major Crossing	Unit Cost	$ 700,000	7	$ 4,900,000
Minor Crossing	Unit Cost	$ 350,000	6	$ 2,100,000
				$ 7,818,750
Southern Channels				
Revised Engineering 1D	Linear Mi.	$ 6,500	14	$ 91,000
Excavation	Cubic Yard	$ 5	470,000	$ 2,350,000
Major Crossing	Unit Cost	$ 700,000	12	$ 8,400,000
Minor Crossing	Unit Cost	$ 350,000	1	$ 350,000
				$ 11,191,000
				$ 19,496,250

- **Losses Avoided and Return on Investment:** Under this scenario the flood gate from scenario 1 is in place and it is assumed that the levee protects as it did during the Hurricane Matthew event. The only flooding reflected on the landward side of the levee is due to backwater from the Lumber River at the Jacob Swamp bridge on Alamac Road. Due to the fact that the northern channels would require less excavation and lesser road crossing improvements than the southern channels while providing greater benefits, the losses avoided for the northern and southern channels are broken out separately. The cost savings for reduced annual flood insurance premiums are not included. Losses avoided due to interior channel improvements and installation of a flood gate is shown in Table 10.

Table 10: Preliminary Losses Avoided/Cost for Strategy 3

Area	Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
Northern Channels	$ 7,818,750	$ 15,135,618	$ 39,114,519	1.94	6.94
Southern Channels	$ 11,191,000	$ 2,260,703	$ 3,586,517	0.20	0.52
All Channels	$ 19,496,250	$ 15,665,294	$ 39,328,554	0.82	2.82

Strategy 4 – Diversion of Lumber River Diversion and Bypass Channel Construction

A bypass channel is a feature that diverts flow from a point upstream of an area needing protection to a point on the same river downstream of the area to be protected. The effect is to reduce discharges and water surface elevations in critical locations. A bypass channel generally remains dry and is only activated during flood events through use of a diversion structure.

- **Channel Flow Path:** The orientation of the Lumber River makes a bypass channel an option to consider as a portion of the flood flows could be diverted west of the City of Lumberton and then rejoin the Lumber River southwest of the City. For this feasibility assessment the path for such a diversion is roughly along the current path of Little Jacob Swamp and then into Jacob Swamp and under Alamac Road (SR 2289) and Highway 72 at the current Jacob Road Crossings. This path is illustrated on the map insert titled "Vicinity Map: City of Lumberton"

  Using this draft configuration, the bypass would be approximately 8.3 miles in length and would require upgraded road crossings at seven locations including Highway 72, Kite Road (SR 2305), Alamac Road (SR 2289), Lovette Road (SR 2204), Martin Luther King Jr. Drive (HWY 41), KB Road (SR 2413), and Contempora Drive. Additionally and significantly, a crossing under I-95 would either need to be constructed or tunneled.

- **Diversion Structure:** In order for the bypass to be functional, a bypass structure would need to be constructed which would likely consist of a low water opening spanning portions of the Lumber River floodplain that would help funnel flood discharges across a lateral weir and into the bypass channel during a flood event. Hardened structures would need to be used in order to enable the accurate prediction and control of flood flows into the bypass. A typical design is shown in Figures 17 and 18 but other variations are conceivable.

Figure 17: Diversion Structure Under Normal Flow Conditions

Figure 18: Diversion structure during flood conditions

- **Sizing the Channel:** The underpass at VFW Road and the low point along I-95 approximately 1,700 feet southwest of the underpass were chosen as critical points to evaluate. These locations are identified in Figure 19. Using the preliminary HEC-RAS model it was determined that approximately 3,000 cfs would need to be diverted to prevent the underpass from being inundated and approximately 5,000 cfs would need to be diverted in order for the low point on I-95 to achieve the required 3 feet of freeboard for levee system certification.

Figure 19: Critical Water Surface Locations

In order to determine an appropriate size for the bypass channel, a HEC-RAS model was developed. Channel inverts were determined based on the invert profile established in the Jacob Swamp Watershed Improvement Plan as constructed by the NRCS for Little Jacob Swamp and Jacob Swamp canals. Various bottom widths were tested and the results were mapped to determine the approximate channel size that would be required to convey the desired discharges. It is important to note that the channel depth is limited and channel slope is set by the upstream and downstream floodplain elevations for the Lumber River. The limited available depth and mild slope limits depth of flow and velocity, necessitating a very wide channel to convey the desired diversion volumes. If the diverted water escapes into the overbank, it has the potential to cause flooding due to the flat terrain.

<u>Test Case 1 - Channel Bottom Width 150’</u>

A constructed channel with a bottom width of 150’ is sufficient to convey an additional 3,000 cfs with minor overbank flooding. With a 4,000 cfs diversion there would be moderate flooding and likely impact some structures as shown in Figure 20. At 5,000 cfs the flooding from the bypass channel would be significant and impact multiple structures that would otherwise not be flooded.

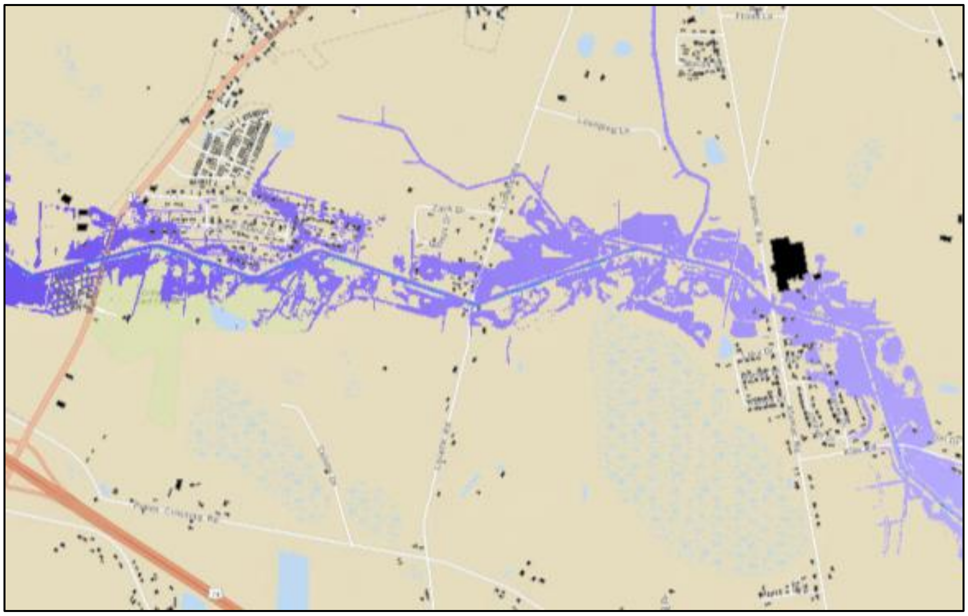


Figure 20: Moderate Overbank Flooding with 4,000 cfs Diversion and 150’ Channel Width

<u>Test Case 2 - Channel Bottom Width 225’</u>

A channel with bottom width of 225’ appears to convey 4,000 cfs without significant overbank flooding. Minor to moderate flooding would be experienced with a 5,000 cfs diversion and would likely not result in additional structures being flooded above those that would flood from Lumber River backwater as shown in Figure 21.

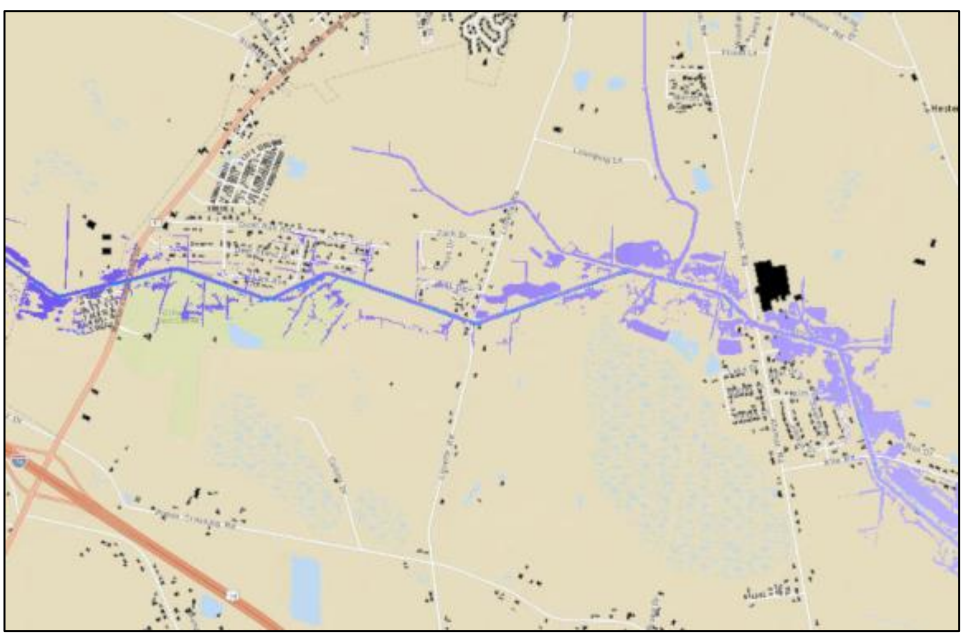


Figure 21: Some Overbank Flooding Occurs with 5,000 cfs Diversion and 225’ Channel Width

<u>Test Case 3 - Channel Bottom Width 300’</u>

A channel with a bottom width of 300’ can convey the 5,000 cfs diversion with only minor overbank flooding as shown in Figure 22.

Figure 22: Very Minor Overbank Flooding with 5,000 cfs Diversion 300' Channel Width

Based on the three test case runs, increasing the channel width by 75 feet will allow for an increase in diversion capacity of approximately 1,500 cfs. Additional details of the channel sizing analysis can be found in Appendix A: Supporting Data.

- **Additional Considerations:** If a berm were constructed on both sides of the bypass channel for the length of the channel, this could substantially increase capacity even with a berm height of 2 to 3 feet. This would also help with the issue of disposal of the fill material. Consideration would have to be made as to whether to try and have the berm accredited as a protecting structure on both sides of the entire 8 mile reach. This would require a higher berm in order to satisfy the 3 foot freeboard requirement. Constructing this length of levee would be a significant cost and require ongoing maintenance funding.

  It is also important to note that any bypass channel would be operating at a time when the Lumber River is flooded at the outlet of the bypass. The backwater impacts from the Lumber River may have significant impacts on the channel conveyance and were not considered with this conceptual analysis. Additional study of this issue is warranted prior to further pursuit of this option.

- **Benefits and Challenges of a Bypass Channel**

  Assuming a 5,000 cfs diversion would decrease the discharge at the Lumberton gage by 5,000 cfs, the water surface at the gage decrease approximately 2.3' based on the HEC-RAS model. While a decrease in the water surface of 2.3' would be beneficial for reduction of flooding along the Lumber River between 2nd Street and S. Chippewa Street, this reduction would not likely be sufficient to open significant additional area for commercial development. Some benefit from reduction in flooding may be seen in areas north of I-95.

  The bypass channel and easement could be a recreational opportunity with potential for greenway paths, recreational areas, and other park-like amenities within the footprint.

  The construction of a bypass channel would present numerous challenges which would need in depth study including:

- Environmental concerns including protected species, wetland offsets, and changing of flood load through the bypassed reach
- Property acquisition and community buy-in
- Installation of crossing for I-95 as well as six other NCDOT maintained roads
- Maintenance of wide channel bed experiencing infrequent flows
- Construction of diversion structure on section of river designated as a state park due to wild and scenic nature
- Disposal of excavated material estimated at 1.7M cubic yards for a 150' wide channel

- **Strategy Costs**

Estimated costs for strategy 4 can be found in Table11 below. This assumes a 150' wide channel

Table 11: Estimated Costs for Strategy 4 – Lumber River Diversion and Bypass Channel

Description	Units	Unit Rate	Quantity	Item Cost
Diversion Structure				
Dewatering and Excavation	Cubic Yard	$ 25	15,000	$ 375,000
Base slab	Cubic Yard	$ 500	3,800	$ 1,900,000
Cutoff and Side Walls	Cubic Yard	$ 500	1,150	$ 575,000
Riprap Protection	Cubic Yard	$ 200	2,500	$ 500,000
Main Dam	Cubic Yard	$ 50	34,000	$ 1,700,000
Gate Structure	Unit Cost	$ 4,500,000	1	$ 4,500,000
Sluiceway	Cubic Yard	$ 500	1,250	$ 625,000
Walls	Cubic Yard	$ 500	50	$ 25,000
Riprap Protection	Cubic Yard	$ 150	350	$ 52,500
Design and Permitting	Unit Cost	$ 3,500,00	1	$ 3,500,000
Bypass Channel				
I-95 Bridge or tunnel	Unit Cost	$ 15,000,000	1	$ 15,000,000
Bridge at DOT Roads	Unit Cost	$ 1,300,000	6	$ 7,800,000
Property Acquisition	Acre	$ 1,500	400	$ 600,000
Excavation	Cubic Yard	$ 5	1,700,000	$ 8,500,000
Channel Lining and Finishing	Sq. Ft	$ 2.50	7,400,000	$ 18,500,000
Design and Permitting	Unit Cost	$ 4,000,000	4,000,000	$ 4,000,000
				$ 68,152,500

- **Losses Avoided and Return on Investment:** Losses avoided are based on modeling and mapping provided by NCEM and are calculated based on expected damages from a 1 percent annual chance flood event. This scenario assumes the levee performs as it did during the Hurricane Matthew event.

Table 12: Preliminary Losses Avoided/Cost for Strategy 4

Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
$ 68,152,500	$ 13,150,024	$ 65,653,429	0.19	1.16

Strategy 5 – Construction of Impoundment on Raft Swamp

Raft Swamp discharges into the Lumber River approximately 1.2 miles upstream of the Lumber River/I-95 crossing. With a drainage area of 172 square miles and an estimated 1% annual chance discharge of 5,076 cfs, it is a significant watershed. Reduction of the peak discharge from Raft Swamp into the Lumber River could significantly impact flood flows through the City of Lumberton, reducing the Lumber River water surface elevations and thereby mitigating flooding issues during a 1% annual chance event. In order to reduce the peak flow, an impoundment structure could be built. In addition to flood mitigation, a lake in the vicinity of the City would help meet recreation needs for the community.

- **Locations for storage:** For this strategy, a hypothetical dam placement approximately 3,200 feet downstream of the confluence of Richland Swamp and Raft Swamp was assumed. The stream invert at this location is approximately 125' based on LiDAR returns. Figure 23 shows the location of the proposed lake.

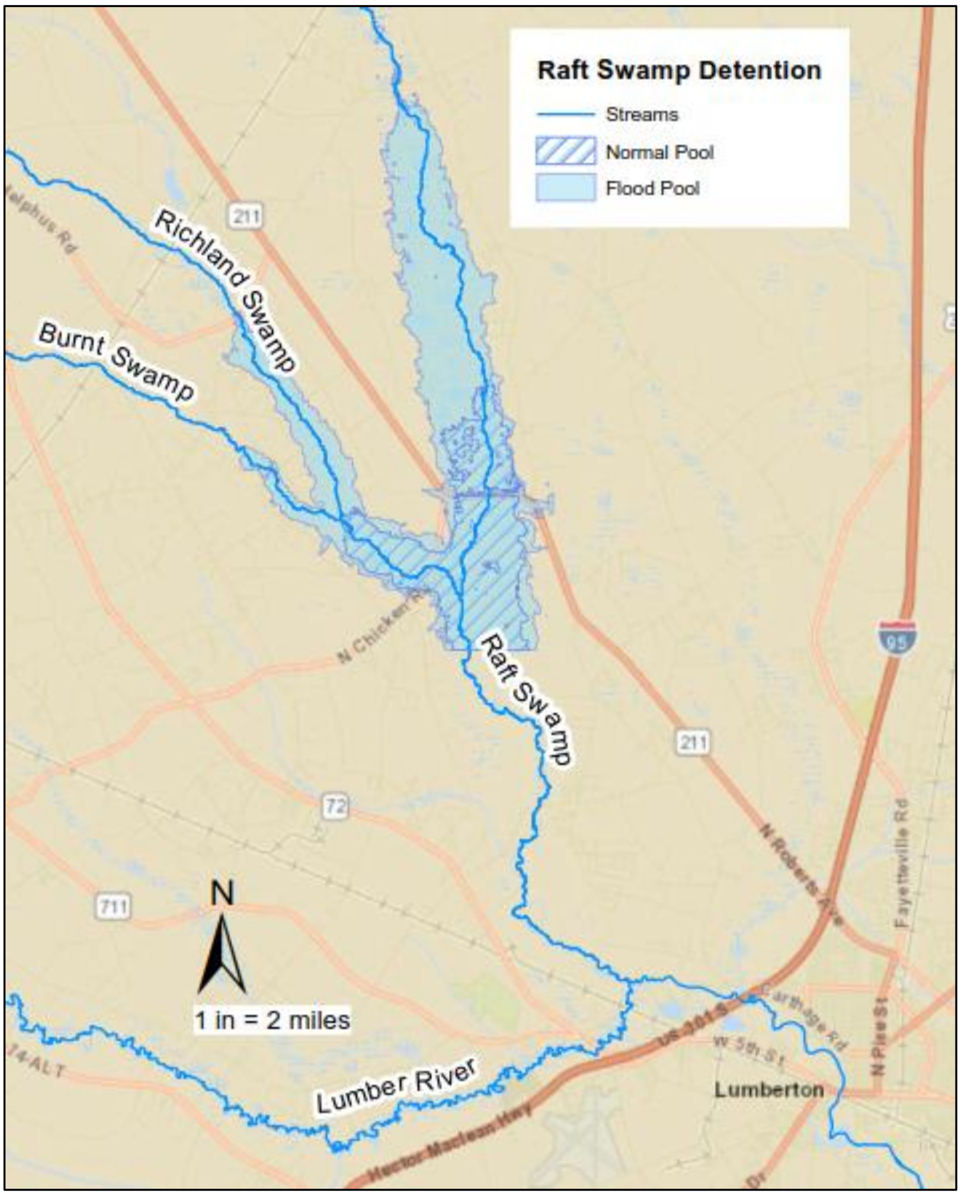


Figure 23: Location of Proposed Storage Facility on Raft Swamp

Table 13 shows estimates of parameters for a dam constructed to retain water to an elevation of 152' (depth at dam of 27') assuming no excavation is performed for the water body.

Table 13: Approximate Dam Parameters for Raft Swamp Impoundment

Water Surface Elevation	Lake Area (acres)	Storage Capacity (Ac-ft.)	Dam Length (ft.)	Average Depth (ft.)	Structures	Building Value (Thousands)
126	13	3	4,800	0.2	0	-
128	88	95	4,800	1.1	0	-
130	304	457	4,800	1.5	0	-
132	590	1,358	4,800	2.3	0	-
134	1,054	2,974	4,800	2.8	0	-
136	1,394	5,444	4,800	3.9	4	515
138	1,751	8,533	4,800	4.9	6	859
140	2,151	12,446	5,000	5.8	8	1,211
142	2,656	17,286	5,000	6.5	10	1,320
144	3,073	23,020	5,200	7.5	11	1,603
146	3,503	29,591	5,900	8.4	19	2,588
148	3,967	37,081	7,800	9.3	25	3,039
150	4,494	45,496	15,300	10.1	42	10,694
152	5,142	55,152	16,500	10.7	75	14,425

Based on examination of the area, it was determined that 148' is a reasonable maximum for the flood pool storage. In order to provide recreational benefit for the community, a reasonable depth will need to be maintained at the normal pool elevation. A normal pool elevation of 138' would result in an average lake depth of approximately 4.9' with approximately 20% of the lake having a depth of less than 2 feet. This is shallow, but should allow for water activities such as fishing and boating using light sail boats or canoes and kayaks. In addition, park amenities could be established such as play areas, shelters and picnic facilities, and hiking/biking trails. Additional study would need to be undertaken to help assess sediment loads and determine a sedimentation rate for the lake. Sedimentation could significantly impact the ability of the lake host recreational activities.

With a normal pool elevation of 138' and a flood storage pool of 148', the impoundment on Raft Swamp could capture a volume of approximately 28,500 acre-feet of flood water.

- **Hydrograph Development**

A hydrograph is a plot of flow rate versus time that describes the total discharge volume during a storm event. Typically, a hydrograph is developed using stream flow records collected at a stream gage. Since Raft Swamp is not a gaged stream, a flood event hydrograph must be estimated using flow records from flood events on a nearby gaged stream. For this scenario, the gage on Big Swamp near Tarheel, NC (USGS station number 02134480) was chosen due to similar drainage area, topography, and land cover. Using this nearby gage it was estimated that for a 1% annual chance flood event on Raft Swamp, total discharge volume would be approximately 59,900 acre-feet. Additional details on this analysis can be found in Appendix A.

- **Volume to be Captured**

  With a storage capacity of approximately 28,500 acre-feet, the impoundment would be capable of capturing discharges on Raft Swamp in excess of approximately 3,500 cfs. The computed 1% annual chance flood discharge for Raft Swamp is 5,080 cfs. This implies a maximum reduction in the peak discharge at the Lumberton gage of approximately 1,600 cfs. Since the Raft Swamp watershed is smaller than the Lumber River watershed at Lumberton, it is likely that Raft Swamp will peak prior to the Lumber River and therefore the reduction to the Lumber River peak would be some value less than 1,600 cfs.

  Assuming the full 1,600 cfs is realized, the peak discharge at the 5th Street gage for the Lumber River 1% annual chance event would be reduced from 14,900 cfs to 13,400 cfs due to the impoundment. This discharge reduction would result in a reduction in water surface at the gage of approximately 0.7'and a water surface reduction of approximately 0.8' at the VFW Road underpass.

- **Strategy Costs:** Table 14 shows estimated costs to implement strategy 5. A flood gate at VFW Road is included in this cost estimate since the storage facility would likely not prevent overtopping of VFW Road.

Table 14: Estimated Costs for Strategy 5 – Storage Facility on Raft Swamp

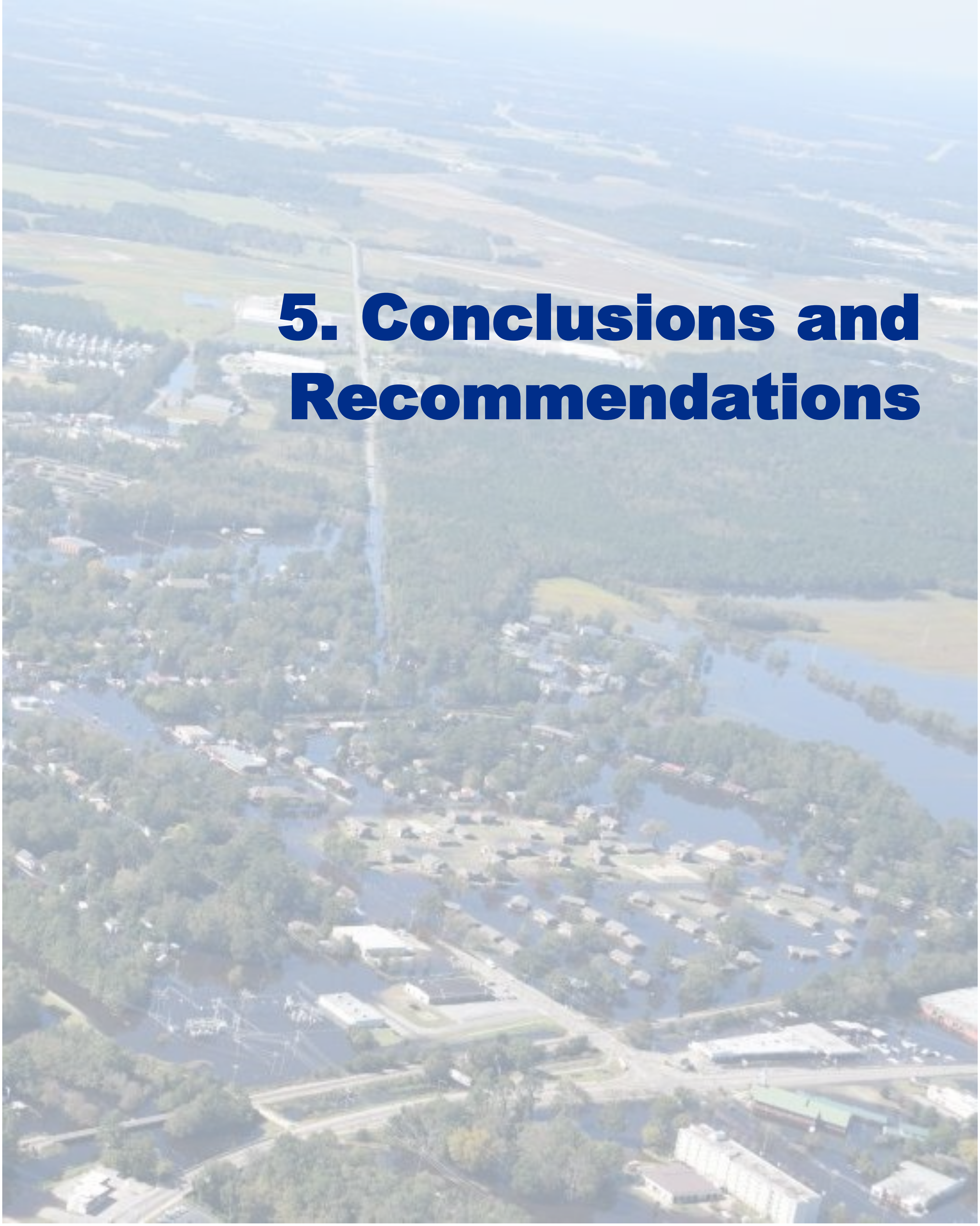
Description	Units	Unit Rate	Quantity	Item Cost
VFW Road Closure	Lump Sum	$ 486,500	1	$ 486,500
Clear and Grub	Acre	$ 3,000	1,900	$ 5,700,000
Control Structure	Lump Sum	$ 8,000,000	1	$ 8,000,000
Earthwork	Cubic Yard	$ 40	538,000	$ 21,520,000
Design and Permit	Lump Sum	$ 5,000,000	1	$ 5,000,000
Structure Acquisition	Per	$ 190,000	75	$ 14,250,000
Property Acquisition	Acre	$ 1,000	5150	$ 5,150,000
Recreation Facilities	Lump Sum	$ 200,000	1	$ 200,000
				$ 60,306,500

- **Losses Avoided and Return on Investment:** Losses avoided on this strategy are shown in Table 15.

Table 15: Preliminary Losses Avoided/Cost for Strategy 5

Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
$ 60,306,500	$ 7,720,836	$ 31,452,438	0.13	0.52

5. Conclusions and Recommendations



5. Conclusions and Recommendations

The flooding in the City of Lumberton as a result of Hurricane Matthew is the result of undersized interior drainage channels, an inflow at the VFW Road underpass that likely exceeded 700 cfs and continued for a period of several days, and backwater flooding from the Lumber River through the Jacob Swamp bridge on Alamac Road (SR 2289). Table 16 below shows a comparison of the costs and losses avoided for each of the mitigation scenarios that were investigated.

Table 16: Comparison Table for Losses Avoided/Cost

Strategy	Cost of Strategy	Losses Avoided (Direct)	Losses Avoided (Indirect)	Direct Losses Avoided/Cost	Total Losses Avoided/Cost
Strategy 1 – Installation of Flood Gate	$ 486,500	$ 1,913,049	$ 3,453,755	3.93	11.0
Strategy 2 – Enhancements to Levee	$ 3,441,500	$ 1,913,049	$ 3,453,755	0.56	1.56
Strategy 3 – Improvements to Interior Drainage	$ 19,496,250	$ 15,665,294	$ 39,328,554	0.82	2.82
Northern Channels	$ 7,818,750	$ 15,135,618	$ 39,114,519	1.94	6.94
Southern Channels	$ 11,191,000	$ 2,260,703	$ 3,586,517	0.20	0.52
Strategy 4 – Diversion of Lumber River	$ 68,152,500	$ 13,150,024	$ 65,653,429	0.19	1.16
Strategy 5 – Construction of Impoundment on Raft Swamp	$ 60,306,500	$ 7,720,836	$ 31,452,438	0.13	0.52

While further study is warranted, it is recommended that plans for construction of a flood gate at the VFW Road underpass be made the priority as it is the lowest cost option and has the greatest potential for preventing devastating flooding like what was seen with Hurricane Matthew. The inflow of water at the underpass exacerbated the flooding, particularly in the area to the northeast of the railroad where water was trapped and unable to evacuate effectively through the Collection Canal culverts due to high backwater in the Collection Canal and on the Lumber River. This resulted in deep and longstanding floodwaters that impacted critical infrastructure such as the water treatment plant. While plans for installation of the flood gate are being made it is recommended that a temporary solution, such as HESCO baskets, be implemented.

Engineering analysis for the interior drainage channels should be revised using improved terrain data and engineering models. Following this analysis, consideration should be given to completing improvements to restore 1% annual chance flood protection to the area. These channel improvements are listed as the #3 priority in the county in the Resilient Redevelopment Plan (RRP). The channels to the north, which include Cotton Mill Branch, Collection Canal, and Gum Branch, are in the areas that are highly developed and would benefit most from channel improvements based on existing engineering analysis and mapping.

Following revised engineering analysis, consideration should be given to seeking certification and accreditation for the levee system. With the flood gate in place the levee system would likely protect the area behind the levee during a 1% annual chance event, but there are still uncertainties in the hydrologic analysis and potential for a failure due to reasons listed in this document such as substandard utility crossings. Certification would provide confidence in the protection level for the community and could spur development. Accreditation would benefit those currently in the special flood hazard area by way of lower insurance rates.

Both the bypass channel and Raft Swamp detention options will have a high cost, involve many environmental and technical complications, and result in limited benefit to the community. Neither of these options is recommended for further investigation.

Work performed for this planning level analysis of flood mitigation strategies in the City of Lumberton was completed by AECOM Technical Services of North Carolina, Inc. for North Carolina Emergency Management. All calculations and drawings contained in this report and associated appendices are concept and are not to be used for construction.

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